

SECTION 4

DEVELOPMENT OF CORRECTIVE MEASURES FOR VOLATILE ORGANIC COMPOUNDS (VOCs)

The principal COCs that have impacted environmental media at Berkeley Lab are halogenated non-aromatic VOCs. These chemicals are primarily solvents such as TCE and PCE, and their byproducts resulting from the natural degradation of the original solvent chemicals. Aromatic VOCs are also present in the soil and groundwater, primarily as the result of fuel leaks from underground storage tanks.

The following subsections include a discussion of the selection of proposed cleanup criteria (Section 4.1); the evaluation of “global” issues that pertain to all of the sites where VOCs are the potential concern, including screening of corrective measure technologies and development of corrective measure alternatives (Section 4.2); and the site-specific detailed evaluations of corrective measures for VOC-impacted soil and groundwater (Section 4.3). The soil and groundwater units at which VOCs are the COCs are listed in **Table 4-1**.

Table 4-1. Soil and Groundwater Units with VOCs as Chemicals of Concern

Unit
Building 51/64 Groundwater Solvent Plume
Building 51L Groundwater Solvent Plume and Source Area
Building 71 Groundwater Solvent Plume Building 71B lobe
Building 7 Lobe of the Old Town Groundwater Solvent Plume and Source Area Former Building 7 Sump
Building 52 Lobe of the Old Town Groundwater Solvent Plume
Building 25A Lobe of the Old Town Groundwater Solvent Plume
Solvents in Groundwater South of Building 76
Building 69A Area of Groundwater Contamination
Building 75/75A Area of Groundwater Contamination
Building 77 Area of Groundwater Contamination
Benzene Detected in Wells East of Building 75A

4.1 MEDIA CLEANUP STANDARDS

4.1.1 Media Cleanup Standards for Groundwater

Media cleanup standards for groundwater were developed for the following VOCs that were detected at concentrations above MCLs during Fiscal Year 2003 (FY03) (October 1, 2002 through September 30, 2003).:

- benzene
- carbon tetrachloride
- chloroform
- 1,1-dichloroethane (1,1-DCA)
- 1,2-dichloroethane (1,2-DCA)
- 1,1-dichloroethene (1,1-DCE)
- cis-1,2- dichloroethene (cis-1,2-DCE)
- trans-1,2- dichloroethene (trans-1,2-DCE)
- 1,2 dichloropropane
- methylene chloride
- 1,1,1-trichloroethane (1,1,1-TCA)
- 1,1,2-trichloroethane (1,1,2-TCA)
- tetrachloroethene (PCE)
- trichloroethene (TCE)
- vinyl chloride.

4.1.1.1 Risk-Based MCSs

The proposed risk-based MCSs for COCs in groundwater are listed in **Table 4.1.1-1**, along with the maximum COC concentrations detected in FY03. The target MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-6} or an HQ of 1, for all potential exposure pathways. The upper-limit MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-4} or an HQ of 1, for all potential exposure pathways. The only COCs that exceeded the proposed risk-based MCSs in FY03 are carbon tetrachloride, PCE, TCE, and vinyl chloride. The risk drivers for these COCs are the volatilization of groundwater COCs and subsequent migration into indoor air, where potential future indoor workers might be exposed; and for TCE only, dermal contact with groundwater by intrusive construction workers. An additional MCS is therefore provided for TCE for units where the intrusive construction worker could potentially be exposed (i.e., the depth to groundwater is less

than or equal to 20 feet). The risk calculations assumed a conservative depth to groundwater of 5-feet at all locations for the inhalation pathway, and used the same default parameters as were used in the HHRA, with the exceptions described in Section 3.

Table 4.1.1-1. Proposed Risk-Based MCSs for VOCs in Groundwater

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Proposed Risk-Based MCSs	
		Target Groundwater MCS Based on Theoretical ILCR=10 ⁻⁶ and HI = 1 (µg/L)	Upper-Limit Groundwater MCS Based on Theoretical ILCR = 10 ⁻⁴ and HI = 1 (µg/L)
benzene	47	175	17,514
carbon tetrachloride	4,600	27	1,004 ^(c)
chloroform	196	1,206	120,582 ^(a) 38,838 ^{(b) (c)}
1,1-DCA	15,800	3,663	366,345
1,2-DCA	75	1,030	102,956
1,1-DCE	2,210	28,873 ^(c)	28,873 ^(c)
cis-1,2-DCE	1,240	98,405 ^(c)	98,405 ^(c)
trans-1,2-DCE	469	94,405 ^(c)	94,405 ^(c)
1,2-dichloropropane	9.4	1,071	15,302 ^(c)
methylene chloride	1,600	10,381	1,038,071
1,1,1-TCA	277	1,570,783 ^(c)	1,570,783 ^(c)
1,1,2-TCA	37	1,905	190,489 ^(a) 61,026 ^{(b) (c)}
PCE	76,035	343	25,265 ^(c)
TCE	79,300	1,594	1,159,365 ^(a) 3,065 ^{(b) (c)}
Vinyl chloride	835	12	1,213

(a) MCS is applicable where groundwater >20 feet.

(b) MCS is applicable where groundwater ≤ 20 feet (based on potential risk to intrusive construction worker).

(c) MCS is based on HI = 1; all other MCSs based on theoretical ILCR = 10⁻⁴.

Note: Boldface concentration values indicate that the maximum detected concentration of the COC in FY03 was above the proposed target risk-based MCS.

To ensure that the presence of multiple chemicals at any unit would not result in unacceptable additive risks, maximum site-wide detected concentrations of chemicals were evaluated. As shown in **Table 4.1.1-1**, maximum detected concentrations of only five COCs exceeded risk-based MCSs. The maximum detected concentrations of other COCs were well below (generally at least an order of magnitude lower than) risk-based MCSs, so these COCs do

not contribute significantly to risk. If all five chemicals that are currently present at concentrations exceeding the MCS were remediated to achieve their respective target MCSs, then the theoretical ILCR would be approximately 5×10^{-6} , which is within the USEPA risk management range. This “worst case” situation is considered to be very unlikely, since not all COCs are present at every soil unit, and the relative proportions of different COCs are sufficiently different that remediation to achieve MCSs would result in concentrations of all but the primary risk-driver COC being reduced to substantially less than their risk-based MCSs. The maximum site concentration of only one COC (TCE) exceeds the risk-based MCS based on the hazard index and all other COCs for which the risk-based MCS is based on the hazard index are present at concentrations several orders of magnitude lower than their hazard index. Therefore, the additive risks for these chemicals are not significant.

4.1.1.2 Regulatory-Based MCSs

MCLs are the proposed regulatory-based MCSs for VOCs in groundwater where the groundwater is a potential source for domestic water supply (i.e., source can provide sufficient water to supply a well capable of producing 200 gpd and they are achievable through Best Management Practices or best economically achievable treatment practices). Proposed regulatory-based MCSs (MCLs) for groundwater are listed in **Table 4.1.1-2**. Also listed in the table is the maximum concentration of each COC detected in groundwater during FY03.

Table 4.1.1-2. Proposed Regulatory-Based MCSs for VOCs in Groundwater

Groundwater COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Proposed Regulatory-Based Groundwater MCS (MCL) (µg/L)
benzene	47	1.0
carbon tetrachloride	4,600	0.5
chloroform	196	100
1,1-DCA	15,800	5
1,2-DCA	75	0.5
1,1-DCE	2,210	6
cis-1,2-DCE	1,240	6
trans-1,2-DCE	469	10
1,2-dichloropropane	9.4	5
methylene chloride	1,600	5
1,1,1-TCA	277	200
1,1,2-TCA	37	5
PCE	76,035	5
TCE	79,300	5
vinyl chloride	835	0.5

4.1.2 Media Cleanup Standards for Soil

Media cleanup standards for soil were developed for those VOCs that the HHRA (Berkeley Lab, 2003a) concluded were present in soil at concentrations above the de minimis level (i.e., theoretical ILCR > 10^{-6} or HI > 1), and for the groundwater COCs (Section 4.1.1) that have been detected in soil at Berkeley Lab. The later criterion was included so that the soil MCSs would be set at levels that are protective of groundwater MCSs (i.e., consider the cross-media transfer of contaminants).

Following is the list of the soil COCs. Except for 1,2-dichloropropane and 1,1,2-TCA, which are only groundwater COCs, the soil and groundwater COCs are the same.

- benzene
- carbon tetrachloride
- chloroform
- 1,1-dichloroethane (1,1-DCA)
- 1,2-dichloroethane (1,2-DCA)
- 1,1-dichloroethene (1,1-DCE)

- cis-1,2- dichloroethene (cis-1,2-DCE)
- trans-1,2- dichloroethene (trans-1,2-DCE)
- methylene chloride
- 1,1,1-trichloroethane (1,1,1-TCA)
- tetrachloroethene (PCE)
- trichloroethene (TCE)
- vinyl chloride.

4.1.2.1 Risk-Based MCSs

The proposed risk-based MCSs for soil are listed in **Table 4.1.2-1**. Also listed in the table is the maximum concentration of the COC that has been detected in soil at Berkeley Lab. The target MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-6} or an HQ of 1, for all potential exposure pathways. The upper-limit MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-4} or an HQ of 1, for all potential exposure pathways. The only COCs that exceed the proposed risk-based MCSs are benzene, carbon tetrachloride, PCE, and TCE. The 1 exposure pathway that drives these MCSs is the volatilization of soil COCs and subsequent migration into indoor air, where potential future indoor workers might be exposed.

To ensure that the presence of multiple chemicals at any one site would not result in unacceptable additive risks, maximum concentrations of chemicals detected at the site were evaluated. As shown in **Table 4.1.2-1**, the maximum detected concentrations of only five COCs (benzene, carbon tetrachloride, PCE, TCE, and vinyl chloride) exceed the target risk-based MCS. Benzene exceeds the MCS at only one unit where no other COCs are present. Therefore, only four COCs are present at any one unit at concentrations that potentially contribute to risks at the unit. For COCs that are present at concentrations less than the risk-based target MCSs, the total of the theoretical ILCRs associated with the maximum concentrations is less than 1.4×10^{-6} . In the unlikely event that all four chemicals that are currently present at concentrations exceeding the MCS were remediated to achieve their respective MCSs, the other COCs remained at their current concentrations, and maximum concentrations of all COCs were present at one location, the theoretical ILCR would therefore be less than 5.4×10^{-6} , which is within the USEPA risk management range. This “worst case” situation is considered to be very unlikely, since not all COCs are present at every soil unit, and the relative proportions of different COCs are

Table 4.1.2-1. Proposed Risk-Based MCSs for VOCs in Soil

Soil COC	Maximum Concentration Detected in Soil (mg/kg)	Proposed Risk-Based MCS	
		Target Soil MCS Based on Theoretical ILCR=10 ⁻⁶ and HI = 1 (mg/kg)	Upper Limit Soil MCS Based on Theoretical ILCR = 10 ⁻⁴ and HI = 1 (mg/kg)
benzene	1.2	0.1	6 ^(a)
carbon tetrachloride	10	0.05	1.8 ^(a)
chloroform	0.092	0.28 ^(a)	0.28 ^(a)
1,1-DCA	0.8	1.3	127
1,2-DCA	0.029	0.23	9 ^(a)
1,1-DCE	0.17	8 ^(a)	8 ^(a)
cis-1,2-DCE	3.1	38 ^(a)	38 ^(a)
trans-1,2-DCE	0.45	50 ^(a)	50 ^(a)
methylene chloride	0.3	1.8	184
1,1,1-TCA	11	690 ^(a)	690 ^(a)
PCE	3,000	0.45	45
TCE	60	2.3	225
Vinyl chloride	0.016	0.0035	0.35

Note: Boldface numbers indicate maximum soil concentrations that are above the proposed target risk-based soil MCS.

(a): Denotes MCS based on HI=1. All other MCSs are based on theoretical ILCR.

sufficiently different that remediation to achieve MCSs would result in concentrations of all but the primary risk-driver COC being reduced to substantially less than their risk-based MCSs. Similarly, the risk-based MCS is based on the HQ for only five COCs. Maximum site-wide concentrations of these five COCs are all less than 10% of the MCS with the exception of chloroform, which is present at a concentration of approximately 33% of the MCS. Therefore, additive risks for these chemicals would not result in an HI (sum of HQs) greater than 1.0, and are therefore insignificant.

Remediation of soil to concentrations below risk-based MCSs could be necessary in some cases, in order to meet risk-based groundwater MCSs. This would be the case where residual soil contamination is present at concentrations that are below risk-based MCSs, but could dissolve into groundwater at concentrations exceeding risk-based groundwater MCSs. In order to determine if this criteria is applicable to developing MCSs for soil, Berkeley Lab calculated the COC soil concentrations that could result in groundwater concentrations at the risk-based MCS level, according to USEPA soil screening guidance (USEPA, 1996b). The linear soil/water

partitioning equation for saturated soil yields the soil COC concentrations (C_t) in equilibrium with its concentration in groundwater at the risk-based levels. The calculated C_t soil concentrations are listed in **Table 4.1.2-2** for each soil COC together with the corresponding risk-based MCSs for soil from **Table 4.1.2-1**. The equilibrium values of C_t are approximately one order of magnitude or more greater than the risk-based soil MCSs, and were therefore not considered any further for setting proposed soil MCSs.

Table 4.1.2-2. Estimated Soil Concentrations in Equilibrium with Risk-Based MCSs for Groundwater

Soil COC	Target Risk-Based Soil MCS ^(a) (mg/kg)	Soil Concentration (C_t) in Equilibrium with Risk-Based Groundwater MCS (mg/kg)
benzene	0.1	1.2
carbon tetrachloride	0.05	0.34
chloroform	0.28	7.2
1,1-DCA	1.3	20.5
1,2-DCA	0.23	5.0
1,1-DCE	8	201
cis-1,2-DCE	38	571
trans-1,2-DCE	50	628
methylene chloride	1.8	47.8
1,1,1-TCA	690	14,922
PCE	0.45	4.1
TCE	2.3	19.9
Vinyl chloride	0.0035	0.06

(a) Proposed risk based soil MCS from Table 4.1.2-1.

4.1.2.2 Regulatory-Based MCSs

Remediation of soil to concentrations below risk-based MCSs may be necessary in some cases, in order to meet regulatory-based groundwater MCSs. This would be the case where residual soil contamination is present at concentrations that are below risk-based MCSs, but could dissolve into groundwater at concentrations exceeding regulatory-based groundwater MCSs (MCLs). In order to determine if this criteria is applicable to developing MCSs for soil at Berkeley Lab, Berkeley Lab considered the guidance provided by the RWQCB in their technical document “Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater” (RWQCB, 2003). The document provides “conservative Environmental Screening Levels for over 100 chemicals commonly found at sites with contaminated soil and groundwater.” The ESLs

include a component that considers soil screening levels for groundwater protection. This component of the ESL soil screening levels addresses potential leaching of chemicals from vadose zone soils and subsequent impact on groundwater and were back calculated based on target groundwater screening levels (i.e., California Primary MCLs where available), and was adopted as the regulatory-based MCS for soil.

The soil screening levels for the protection of groundwater are listed in **Table 4.1.2-3**. Also listed in the table are the target risk-based soil MCSs from **Table 4.1.2-1**. The target risk-based soil MCSs are greater than the proposed regulatory-based soil MCSs for all COCs except for chloroform, carbon tetrachloride, PCE, and vinyl chloride. The soil screening levels are potentially applicable MCSs where the groundwater is a potential source for domestic water supply (i.e., source can provide sufficient water to supply a well capable of producing 200 gpd and they are achievable through Best Management Practices or best economically achievable treatment practices). In those areas, the lesser of the risk-based soil MCS or the soil screening level would be the applicable.

Table 4.1.2-3. Proposed Soil MCSs that are Protective of Regulatory-Based MCSs for Groundwater

Soil COC	Proposed Regulatory-Based Soil MCS for Protection of Beneficial Use of Groundwater ^(a) (mg/kg)	Target Risk-Based Soil MCS ^(b) (mg/kg)
benzene	0.044	0.1
carbon tetrachloride	0.11	0.05
chloroform	2.9	0.28
1,1-DCA	0.2	1.3
1,2-DCA	0.0045	0.23
1,1-DCE	1.0	8
cis-1,2-DCE	0.19	38
trans-1,2-DCE	0.67	50
methylene chloride	0.077	1.8
1,1,1-TCA	7.8	690
PCE	0.7	0.45
TCE	0.46	2.3
vinyl chloride	0.085	0.0035

(a) Soil screening level from RWQCB (2003).

(b) Target risk based soil MCS from Table 4.1.2-2.

Note: Boldface numbers indicate that regulatory based (protection of groundwater) soil MCS is less than the target risk-based soil MCS.

4.1.3 Summary of Media Cleanup Standards for VOCs

Groundwater

Two criteria were considered when developing MCSs for groundwater: potential risk to human health and the impact to the beneficial use of groundwater for domestic supply. The proposed target risk-based MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-6} or an HQ of 1, and are applicable in all areas of Berkeley Lab. The regulatory-based MCSs (MCLs) are based on potential future domestic use, and are applicable to the areas where groundwater constitutes a potential drinking water source based on SWRCB criteria (i.e., well yield is ≥ 200 gallons per day). Since MCLs are less than the risk-based MCSs for all COCs, the risk-based MCSs will apply only in those areas where groundwater is not considered a potential drinking water source. Proposed target MCSs for groundwater and the applicability of the MCSs are listed in **Table 4.1.3-1**.

As discussed in Section 3.4, it is likely that achievement of regulatory-based MCSs (MCLs) will be technically impracticable in many of the areas of groundwater contamination using currently available technology. The effectiveness of the implemented remedial systems in achieving the required MCSs will therefore be reviewed after five years of operation (in 2011). If at that time groundwater concentrations are approaching an asymptotic level above MCLs and the mass of groundwater contaminants that is being removed is not significant, a Determination of Technical Impracticability (TI) will be requested from the DTSC. If the Determination of TI is approved, the regulatory based MCSs will be replaced with the established risk-based MCSs, and the following actions will be implemented.

- Any remaining sources of contamination will be removed or contained
- A monitoring program will be established to demonstrate that containment of groundwater contamination is being maintained.

Soil

Two criteria were considered when developing MCSs for soil: potential risk to human health from the soil pathway and the cross-media transfer of soil COCs to groundwater at concentrations that could result in groundwater MCSs being exceeded. Risk-based soil MCSs

are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-6} or an HQ of 1, either through direct soil pathways or cross-media transfer, and are applicable in all areas of Berkeley Lab. Regulatory-based soil MCSs were developed based the potential to impact groundwater above regulatory-based MCSs (MCLs), and are applicable to areas where groundwater constitutes a potential drinking water source based on SWRCB criteria (i.e., well yield is ≥ 200 gallons per day). In those areas where groundwater is considered a potential drinking water source, the lesser of the risk-based soil concentration or regulatory-based soil concentration is proposed as the MCS. Proposed target MCSs for soil and the applicability of the MCSs are listed in **Table 4.1.3-1**. **Figure I-9 (Appendix I)** shows areas where soil COC concentrations exceed the soil MCSs.

Table 4.1.3-1. Summary of Proposed Media Cleanup Standards (MCSs) for Groundwater and Soil

	Groundwater		Soil	
	Target Risk-Based Groundwater MCS ($\mu\text{g/L}$)	Regulatory-Based Groundwater MCS (MCLs) ($\mu\text{g/L}$)	Target Risk-Based Soil MCS (mg/kg)	Regulatory-Based Soil MCS ^(a) (mg/kg)
Applicability	Well yield is < 200 gpd	Well yield ≥ 200 gpd	Soil overlying areas where well yield is < 200 gpd	Soil overlying areas where well yield ≥ 200 gpd
COC				
benzene	175	1	0.1	0.044
carbon tetrachloride	27	0.5	0.05	0.05*
chloroform	1,206	100	0.28	0.28*
1,1-DCA	3,663	5	1.3	0.2
1,2-DCA	1,030	0.5	0.23	0.0045
1,1-DCE	28,873	6	8	1.0
cis-1,2-DCE	98,405	6	38	0.19
trans-1,2-DCE	94,405	10	50	0.67
1,2-dichloropropane	1,071	5	NA	NA
methylene chloride	10,381	5	1.8	0.077
1,1,1-TCA	1,570,783	200	690	7.8
1,1,2-TCA	1,905	5	NA	NA
PCE	343	5	0.45	0.45*
TCE	1,594	5	2.3	0.46
vinyl chloride	12	0.5	0.0035	0.0035*

(a) The lesser of the risk-based or regulatory based MCS. * indicates MCS is risk based; all other MCSs for soil in areas where well yield is ≥ 200 gpd are regulatory based.

NA: MCS is not applicable. Chemical is not a soil COC.

4.2 SELECTION AND EVALUATION OF CORRECTIVE MEASURES ALTERNATIVES FOR VOCs IN SOIL AND GROUNDWATER

4.2.1 Subdivision of Groundwater Units into Zones

For the purpose of selecting the appropriate corrective measures alternatives for VOCs, some of the Berkeley Lab groundwater units were divided into distinct zones. Different remedial strategies may be applicable to each defined zone in the same groundwater unit because of the relative concentrations and different phases of halogenated VOCs present.

- The plume source zone contains DNAPL and/or relatively high concentrations of COCs in the soil that constitute a continuing source of groundwater contamination.
- The plume core zone contains COCs in the groundwater at concentrations greater than risk-based MCSs, but data do not indicate the presence of DNAPL.
- The plume periphery zone contains COCs in the groundwater at concentrations below risk-based MCSs, but greater than regulatory-based MCSs [e.g., MCLs]).

The plume source zone is defined as the area that contains DNAPL and/or concentrations of VOCs in vadose zone soils that exceed the RWQCB soil screening levels for groundwater protection (RWQCB, 2003). Dissolved concentrations of groundwater COCs in the source zone are largely controlled by the balance between the original contaminant concentration in soil matrices, the continued dissolution of COCs into groundwater, and the removal of COCs by flushing of upgradient groundwater (or for existing systems, the flushing of injected water through the saturated zone). For some of the Berkeley Lab units, the source zone is no longer present due to low initial contaminant concentrations and/or the natural attenuation of residual soil contamination and DNAPL.

The plume core zone is defined as the area of the plume where dissolved concentrations of COCs in groundwater exceed risk-based MCSs, the analytical data do not indicate the presence of DNAPLs, and concentrations of VOCs in vadose zone soils do not exceed the RWQCB soil screening levels for groundwater protection (RWQCB, 2003). Dissolved concentrations of COCs in groundwater in the core zone are largely controlled by migration of contaminated groundwater from the upgradient source zone, if present, and the equilibrium

partitioning of COCs between the groundwater and soil. Residual soil concentrations are largely controlled by the equilibrium partitioning of COCs between the groundwater and soil.

The plume periphery is the area of the plume with COC concentrations that are less than risk-based MCSs, but greater than regulatory-based MCSs (i.e., MCLs). Dissolved concentrations of COCs in groundwater in the periphery zone are largely controlled by migration of contaminated groundwater from the source and core zones, if present, and the equilibrium partitioning of COCs between the groundwater and soil. Any reductions in groundwater COC concentrations in the plume periphery would be ineffective unless 1) there is no core or source zone present, 2) concentrations in the core and source zones are first significantly reduced, or 3) hydraulic controls are installed to isolate the plume periphery zone. Cleanup of a plume periphery zone is therefore considered a lower priority than cleanup of the core or source zone, if present. However, as discussed in Section 3, a Corrective Action Objective is to contain contaminated groundwater, so that it does not degrade water quality in adjacent areas. Therefore, existing controls on the migration of groundwater from the plume periphery zone should be maintained to prevent the degradation of groundwater quality in adjacent areas.

Table 4.2.1-1 indicates which of the three zones is present at each of the groundwater units.

Table 4.2.1-1. Source Zone, Core Zone, and Periphery Zones at Groundwater Units

Unit	Plume Source Zone	Plume Core	Plume Periphery
Building 51/64 Groundwater Solvent Plume		√	√
Building 51L Groundwater Solvent Plume	√	√	√
Building 71 Groundwater Solvent Plume Building 71B lobe	√	√	√
Building 7 lobe of the Old Town Groundwater Solvent Plume	√	√	√
Building 52 lobe of the Old Town Groundwater Solvent Plume			√
Building 25A lobe of the Old Town Groundwater Solvent Plume		√	√
Solvents in Groundwater South of Building 76			√
Support Services Area (Building 69A Area)			√
Support Services Area (Building 75/75A Area)			√
Support Services Area (Building 77 Area)			
Benzene Detected in Wells East of Building 75A			√

4.2.2 Identification of the Presence of DNAPL

The ability of a corrective measure to effectively remediate contaminated groundwater is a function of a number of variables, one of the most important of which is whether DNAPLs are present. Therefore, it is important to identify where DNAPLs may be present, and, if possible, delineate their extent. Most DNAPL detection methods are subject to “false negatives” (i.e., lack of detection does not indicate absence of DNAPLs), particularly because DNAPL tends to migrate and collect along thin, irregular heterogeneities. In the absence of reliable detection methods, USEPA specifies use of various “rules of thumb” to assess whether DNAPLs are likely to be present (USEPA, 1992). Two of these “rules of thumb” applicable to Berkeley Lab are discussed below.

4.2.2.1 Method 1 -- Comparison of Soil Concentrations with Soil Saturation Concentrations

DNAPL can be presumed to be present in a soil sample when the concentration of a constituent in soil exceeds its soil saturation concentration (sat). The USEPA PRG table lists a default soil saturation concentration value of 230 mg/kg for PCE in vadose-zone soil based on the equation:

$$\text{sat (mg/kg)} = C_{w,\text{sol}} / \rho_b (\rho_b K_d + \theta_w + H' \theta_a)$$

where:

- ρ_b = bulk density (dry mass of soil/volume of soil [kg/m^3]) (assumed value 1.5)
- K_d = $K_{oc}f_{oc}$ = solid/aqueous partition coefficient (m^3/kg);
Where: K_{oc} = organic carbon/aqueous partition coefficient (m^3/kg); $160 \text{ cm}^3/\text{g}$
 f_{oc} = mass fraction of organic carbon in soil (assumed value 0.006)
- $C_{w,\text{sol}}$ = solubility limit of a particular chemical (mg/L)
- θ_w = water-filled porosity
- H' = Henry's Law constant
- θ_a = air-filled porosity.

Based on analyses of soil samples at Berkeley Lab, the mass fraction of organic carbon (f_{oc}) averages approximately 0.0025 and the bulk density is approximately 1.6 or greater. In addition, soils with elevated COC concentrations are primarily present in the saturated zone. For saturated soil, the above equation can be simplified to

$$\text{sat (mg/kg)} = (n + \rho_b K_d) C_{w,\text{sol}}, \text{ where } n = \text{porosity}$$

Using the site-specific values noted above, and assuming a porosity of 0.25, the soil saturation concentration for PCE in saturated soil would be 178 mg/kg, only slightly less than the default value provided in the PRG table. The estimated soil saturation concentrations for soil COCs are listed in **Table 4.2.2-1**, together with the maximum concentrations detected at the units discussed in this report:

Table 4.2.2-1 Soil Saturation Concentrations for Soil COCs

Soil COC	Maximum Concentration Detected (mg/kg)	Default USEPA Soil Saturation Concentration (mg/kg)	Estimated Berkeley Lab Soil Saturation Concentration (mg/kg)
benzene	1.2	1,100	735
carbon tetrachloride	10	1,100	735
chloroform	0.092	2,900	3,239
1,1-DCA	0.8	1,700	1,927
1,2-DCA	0.029	1,800	2,703
1,1-DCE	0.17	1,500	1,118
cis-1,2-DCE	3.1	1,200	1379
trans-1,2-DCE	0.45	3,100	2,911
methylene chloride	0.3	2,500	3,874
1,1,1-TCA	11	1,200	897
PCE	3,071	230	178
TCE	60	1,300	1,023
vinyl chloride	0.016	1,200	913

Note: Boldface number indicates concentration greater than soil saturation concentration.

Only one COC (PCE) has been detected at a concentration above the soil saturation concentration. The concentration exceeds this level only in the source area of the Building 7 Lobe of the Old Town Groundwater Plume, so only this area might have DNAPL present according to this criterion.

4.2.2.2 Method 2 -- Effective Volubility of Constituents in Groundwater

The USEPA (USEPA, 1992) recommends assessing the potential presence of DNAPLs by determining whether concentrations in groundwater exceed 1% of either the pure-phase volubility or the effective volubility (the theoretical upper-level dissolved-phase concentration of

a constituent in ground water in equilibrium with a mixed DNAPL). Where multi-component mixtures are present, USEPA recommends that effective volatility (the solubility multiplied by the mole fraction) be calculated based on the mole fraction of each component in the DNAPL. However, insufficient data are available to allow accurate estimation of mole fractions in potential DNAPLs. Therefore, the potential presence of DNAPL is estimated by comparing the pure-phase volatility (equivalent to the solubility) of COCs with their measured groundwater concentrations. This simplification is unlikely to result in erroneous interpretations of the presence or absence of DNAPLs, although it cannot be used to predict the composition of multi-phase DNAPLs. **Table 4.2.2-2** lists pure-phase volubilities (solubilities) of the soil COCs at Berkeley Lab.

Table 4.2.2-2. Pure-Phase Volubilities of Soil COCs.

Soil COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Pure-Phase Volubility (Solubility) (µg/L)	1% of Solubility (µg/L)
benzene	47	1,800,000	1,800
carbon tetrachloride	4,600	790,000	7,900
1,1-DCA	15,800	7,900,000	79,000
1,2-DCA	75	8,500,000	85,000
1,1-DCE	2,210	2,300,000	23,000
cis-1,2-DCE	1,240	3,500,000	35,000
trans-1,2-DCE	469	6,300,000	63,000
methylene chloride	1,600	13,000,000	130,000
1,1,1-TCA	277	1,300,000	13,000
1,1,2-TCA	37	4,400,000	4,400
PCE	76,035	200,000	2,000
TCE	79,300	1,100,000	11,000
vinyl chloride	835	2,800,000	2,800

Note: Boldface number indicates concentration greater than 1% of solubility.

The data in **Table 4.2.2-2** indicate that only two COCs (PCE and TCE) are present at concentrations greater than 1% of their solubility. Concentrations of these COCs exceed 1% of their solubility only in the Building 7 Lobe of the Old Town Groundwater Plume and the

Building 71B lobe of the Building 71 Groundwater Solvent Plume, so only these areas might have DNAPL present according to this criterion.

4.2.3 Identification of Potentially Applicable Corrective Measures Alternatives

The corrective measures alternatives that are considered potentially applicable to halogenated VOCs in soil and groundwater are listed in **Table 4.2.3-1** and **Table 4.2.3-2**, respectively.

4.2.3.1 Preliminary Screening of Potentially Applicable Corrective Measures Alternatives

A step-wise screening process, as described in **Section 3.3**, was used to evaluate the corrective measures alternatives for VOCs in soil and groundwater at Berkeley Lab. The screening consisted of an evaluation as to whether the method was potentially effective and applicable. Each technology was screened based on a determination as to whether it could meet one or more of the following objectives:

- Remove the source of the groundwater plumes (potentially reduce COC concentrations in the source area where DNAPL and/or residual soil contamination is present)
- Remediate the groundwater plume (potentially achieve MCSs downgradient from the source area)
- Control the COCs in order to protect human health and the environment (e.g., restrict migration of COCs into areas with lower COC concentrations).

The results of the initial screening process are included in **Table 4.2.3-1** and **Table 4.2.3-2**. The retained technologies are discussed in more detail in the following section.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion	
No Action	No Action	No further action of any type	Is not effective in protecting human health.	Implementable	√	Retain for further consideration as a required alternative.
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation (MNA)	Natural subsurface processes - such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials - are allowed to reduce contaminant concentrations to acceptable levels.	Is not effective in protecting human health. Is not effective in reducing COC concentrations in soil over a reasonable time frame.	Implementable	X	Eliminate from current consideration based on effectiveness.
Risk and Hazard Management	Institutional Controls (physical barriers or markers)	Signs, fencing and/or other barriers designed to reduce or eliminate human exposure to COCs	May be effective in protecting human health. Is not effective in reducing COC concentrations.	Implementable.	√	Retain for further consideration
	Institutional Controls (legal or administrative)	Administrative or legal restrictions such as deed restrictions or permit requirements that limit activities (such as construction of buildings) that might result in human exposure to COCs	May be effective in protecting human health. Is not effective in reducing COC concentrations.	Implementable.	√	Retain for further consideration.
Containment	Capping Solidification Stabilization	A surface cover is placed over the contaminated soil (capping). Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Effective in protecting human health. Containment measures can also limit surface water infiltration and leaching of contaminants to groundwater. Not effective in reducing COC concentrations.	Implementable.	√	Retain for further consideration.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion
Remedial Technologies	In situ treatment				
	Enhanced bioremediation	The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance in situ biological degradation of organic contaminants. Nutrients, oxygen, or other amendments may be used.	May not be effective in reducing COC concentrations in low permeability or heterogeneous soils. Preferential flow paths may severely decrease contact between injected fluids and contaminants. Remediation times are often years, depending mainly on the degradation rates of specific contaminants, site characteristics, and climate.	Not implementable in low permeability and/or high moisture content soils such as the Mixed Unit. May be implementable in Moraga Formation or in surficial units, but soil COCs are generally sparse in those units.	X Eliminate from consideration based on effectiveness.
	Phytoremediation	Phytoremediation is a set of processes that use plants to clean contamination in soil, ground water, surface water, sediment, and air.	Effective in reducing COC concentrations only in shallow contaminated soils. Can also transfer contamination cross media (soil to air). High concentrations of contaminants in plume source areas may be toxic to plants.	Not implementable in Berkeley Lab source areas because areas are developed and in some locations groundwater is too deep.	X Eliminate from further consideration based on implementability.
	Bioventing	Air is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.	Not effective in reducing concentrations of VOCs.	Implementable	X Eliminate from further consideration based on effectiveness.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion
Remedial Technologies (cont'd.)	In situ treatment (cont'd.)				
	Chemical oxidation	Reduction/oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.	Limited effectiveness in reducing COC concentrations in heterogeneous and/or low permeability soil because it requires intimate contact of the reagent with the source solvent.	Pilot testing has indicated that the method is implementable.	√ Retain for consideration.
	Electrokinetic separation	Electrokinetic separation uses electrochemical and electrokinetic processes to desorb, and then remove, polar organics from low permeability soils	Limited effectiveness in reducing COC concentrations due to fractured, heterogeneous nature of the bedrock units. For organic compounds, the method is limited to the soluble fraction and will not remove residual non-aqueous-phase solvents.	Implementability may be limited in source area because of numerous underground utilities.	X Eliminate from further consideration based on effectiveness.
	Extraction with ex-situ treatment				
	Soil vapor extraction (SVE)	Vacuum is applied through extraction wells to create a pressure gradient that induces advection of gas-phase volatiles through soil to extraction wells. The process includes a system for handling off-gases.	Not effective in reducing COC concentrations in low permeability and/or high moisture content soils, so effectiveness is variable, depending on site conditions.	An SVE system has been installed on-site as an ICM.	√ Retain for further consideration

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion
Remedial Technologies (cont'd.)	Extraction with ex-situ treatment (cont'd.)				
	Thermally enhanced SVE/DPE	Heating and groundwater extraction is used to increase volatilization of VOCs and decrease vadose zone moisture content to facilitate vapor removal. The heating can be accomplished by conductive heating, electrical resistance/ electromagnetic/fiber optic/radio frequency heating; hot air or steam injection.	High moisture content is a limitation of standard SVE that thermal enhancement may help overcome. This method has been pilot tested in the source area of the Old Town Plume – Building 7 lobe and has proven effective in removing COCs.	This method has been implemented in the source area of the Old Town Plume – Building 7 lobe as a pilot test.	√ Retain for further consideration.
	Fracturing – enhanced SVE	Pressurized air or liquid is injected beneath the surface to develop cracks in low permeability and over-consolidated sediments, opening new passageways that increase the effectiveness of many in situ processes and enhance extraction efficiencies. Sand or granular reactive materials can be injected into the fractures or to keep them open and/or deliver in situ remediation agents.	Effectiveness in reducing COC concentrations at Berkeley Lab is unknown. Artificial fracturing may result in opening of new pathways that may cause the unwanted spread of contaminants into uncontaminated materials.	Not implementable in developed source areas and/or slope stability concerns in some core areas.	X Eliminate from further consideration based on effectiveness and/or implementability.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion
Remedial Technologies (cont'd.)	Extraction with ex-situ treatment (cont'd.)				
	Soil flushing + Groundwater Extraction (water/surfactant/co-solvent)	Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the ground water to raise the water table into the contaminated soil zone. Contaminants are leached into the ground water, which is then extracted and treated.	Soil flushing has low potential effectiveness in reducing COC concentrations in heterogeneous or fine grained/low permeability materials. At Berkeley Lab, flushing and recirculation of treated groundwater has been effective in removing contaminants from beneath the Building 7 sump excavation. Surfactants can adhere to soil and reduce effective soil porosity. Reactions of flushing fluids with soil can reduce contaminant mobility. Surfactant/co-solvent flushing is effective for relatively small and well-defined solvent targets, which have not been located at Berkeley Lab.	Soil flushing with treated groundwater has been implemented as ICMs/pilot tests at several locations at Berkeley Lab. Surfactant/co-solvent flushing should be used only where flushed contaminants and soil flushing fluid can be contained and recaptured.	√ Retain soil flushing with treated groundwater for further consideration. Eliminate surfactant/co-solvent flushing from further consideration based on effectiveness and implementability.
	Soil mixing	The soil is broken up and mixed by drilling, which increases the permeability. The contaminants can be extracted by SVE and/or destroyed by injection of chemical oxidants. Steam can also be simultaneously injected to volatilize the contaminants.	Effectiveness in reducing COC concentrations is not known.	Low permeability materials (e.g., the Mixed Unit) can be broken up and mixed with higher permeability materials (e.g., Moraga Formation or surficial units) to increase the permeability and allow flushing/extraction of the contaminants.	√ Retain for further consideration.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion
Remedial Technologies (cont'd.)	Extraction with ex-situ treatment (cont'd.)				
	Excavation with ex-situ treatment: Biopiles, composting, fungal biodegradation, chemical extraction, chemical oxidation/reduction, dehalogenation, separation, soil washing, hot gas decontamination, incineration, open burn, pyrolysis, and thermal desorption.	Soil is excavated and treated on-site, then reused or transported off-site for disposal.	The methods would be effective in protecting human health and reducing COC concentrations.	Many of the alternatives would not be implementable because of limited area available for treatment.	X Eliminate from further consideration based on implementability
	Excavation and offsite disposal	Contaminated material is removed and transported to permitted off-site treatment and disposal facilities. Pretreatment may be required.	Method has been used at Berkeley Lab and is effective in protecting human health and reducing COC concentrations.	This alternative has been implemented at several ICMs at Berkeley Lab.	√ Retain for further consideration.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
No Action	No Action	No further action of any type.	Is not effective in protecting human health.	Implementable.	Same as source zone.	Same as source zone.	Same as source zone	Same as source zone.	Retain for further consideration as a required alternative.
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation (MNA)	Natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials are allowed to reduce contaminant concentrations to acceptable levels.	Not effective in protecting human health or reducing COC concentrations in areas where DNAPL or high residual soil concentrations are available for dissolution into groundwater	Implementable.	Is not effective in areas where high residual soil concentrations are available for dissolution into groundwater. May be effective in areas of lower contaminant concentrations where site data indicate that natural attenuation processes are occurring.	Implementable.	May be effective in areas where site data indicate that natural attenuation processes are occurring.	Implementable.	Eliminate from consideration in plume source areas and high concentration core area. Retain for further consideration in lower concentration plume core and periphery areas.
Risk and Hazard Management	Institutional Controls (physical barriers or markers)	Signs, fencing, and/or other barriers designed to reduce or eliminate human exposure to COCs.	May be effective in protecting human health. Is not effective in reducing COC concentrations.	Implementable.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Retain for further consideration.
	Institutional Controls (legal or administrative)	Administrative or legal restrictions such as deed restrictions or permit requirements that limit activities (such as construction of buildings) that might result in human exposure to COCs	May be effective in protecting human health Is not effective in reducing COC concentrations. Would likely be required to restrict ground water use prior to achieving regulatory-based MCSs.	Implementable.	Same as source zone.	Same as source zone.	Would be effective if plume migration is controlled. Would likely be required to restrict ground water use prior to achieving regulatory-based MCSs.	Implementable	Retain for further consideration.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Containment and Capture	Containment/diversion (Slurry walls Sheet pile walls Grout curtains)	These methods stabilize groundwater COCs in place by preventing or reducing their migration. Slurry walls consist of trenches filled with a low permeability material., usually a mixture of bentonite and water. Grout curtains consist of the subsurface injection of a cement/bentonite and water mixture to decrease the subsurface permeability.	Not effective in protecting human health or reducing COC concentrations. These methods can be used to decrease the potential for migration of plume boundaries or of high concentration zones within plumes.	Implementable	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration as a remedial technology based on effectiveness. Retain as a plume control measure.
	Groundwater Capture (Drains, Trenches, Extraction wells)	Control measures to prevent further migration of groundwater contaminants by extracting groundwater within and at the downgradient edge of groundwater plumes.	Not effective in protecting human health. The effectiveness in reducing contaminant concentrations is limited by the continued presence of a residual source and the heterogeneity of the subsurface. However, capture is effective in controlling further migration of COCs.	Implementable. Subsurface drains, trenches and extraction wells are being used on site as plume control measures.	Is not protective of human health. Does not reduce COC concentrations except over very long time scales. However, capture is effective in controlling further migration of COCs.	Same as source zone.	Is not protective of human health. Does not reduce COC concentrations except over very long time scales. However, capture is effective in controlling further migration of COCs.	Same as source zone.	Eliminate from further consideration as a remedial technology based on effectiveness. Retain as a plume control measure.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies	In Situ Treatment								
	Permeable Reactive Barrier (PRB) and Funnel and Gate	A permeable wall, containing reactive substances such as sorbents or zero-valent metals, is installed across the flow path of the plume. Contaminants are chemically removed as groundwater flows through the wall. A funnel and gate system can be used to direct the groundwater towards the permeable wall	Not effective because of the relatively high concentrations of COCs in the source zone.	Implementable. Similar implementability to collection trenches which have been installed on site. The reactive element in the barrier would need frequent replacement due to reduced reactive capacity and/or loss in media porosity due to precipitation.	Not effective because of the relatively high concentrations of VOCs in the core zone.	Implementable	Could be effective as a migration control measure in the periphery zone of the plume.	Implementable	Eliminate from further consideration as a remedial technology based on effectiveness. Retain as a plume control measure.
	Chemical Oxidation	A chemical oxidant solution, such as hydrogen peroxide, is injected into the aquifer. The oxidant converts chlorinated VOCs to water, carbon dioxide, and chlorides.	Method has been pilot tested with inconclusive results of effectiveness in reducing COC concentrations. Injecting chemical over a wide area in low permeability soil would likely leave unreacted pockets of contamination. Permanganate could produce byproducts that degrade water quality. Other oxidants (ozone, hydrogen peroxide) would have limited stability in the subsurface, reducing the effective treatment radius.	Would require a significant number of injection wells in the low permeability Mixed Unit core area of the plume.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Retain for further consideration.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies (cont'd.)	In situ treatment (cont'd.)								
	Enhanced bioremediation	<u>Aerobic Oxidation</u> An oxygen release compound (ORC®) is injected into the aquifer to stimulate natural aerobic degradation of contaminants. The amendment could be added via direct injection or groundwater circulation.	Limited effectiveness in reducing COC concentrations because highly chlorinated VOCs (e.g., PCE, TCE) do not degrade well via direct aerobic degradation using ORC technology.	Low groundwater velocities at Berkeley Lab would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	Same as source zone.	Same as source zone.	May be effective in downgradient areas where highly chlorinated VOCs have been degraded to less chlorinated VOCs (e.g., DCE, vinyl chloride) that will not degrade further under site conditions	Low groundwater velocities at Berkeley Lab would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	Eliminate from further consideration based on effectiveness for source and core zones. Retain for further consideration for periphery zone.
		<u>Anaerobic Reductive Dechlorination</u> Contaminants are degraded by native microorganisms, enhanced through the addition of an amendment such as hydrogen release compound (HRC®). The amendment could be added via direct injection or groundwater circulation.	Not effective in reducing COC concentrations in source area due to continued dissolution of DNAPL and residual soil COCs into groundwater	Groundwater velocities at Berkeley Lab would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	May be effective in reducing COC concentrations if anaerobic conditions are present and can be maintained. Amendment might not adequately permeate low permeability or heterogeneous soils. Vinyl chloride could accumulate in some areas.	Groundwater velocities at Berkeley Lab would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	Same as core zone	Same as core zone.	Eliminate from current consideration based on effectiveness for source zones. Retain for further consideration for core and periphery zones.
		<u>Cometabolism</u> Injection of a dilute solution of liquids and/or gases (e.g., toluene, methane or oxygen) into the contaminated ground water zone to enhance the rate of methanotrophic biological degradation of organic contaminants.	Would not be effective in reducing COC concentrations based on results of methanotrophic treatment technology pilot test.	The extremely low groundwater velocity would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on effectiveness.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies (cont'd.)	In situ treatment (cont'd.)								
	Phytoremediation	Phytoremediation is a set of processes that uses plants to clean contamination, particularly organic substances, in ground water and surface water.	Effectiveness in reducing COC concentrations is limited to shallow depths (most contamination is at greater depths i.e.,10 ft or more).	Plume source areas are developed, so planting of appropriate vegetation would not be possible in most locations.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on effectiveness and implementability.
	Extraction with ex-situ treatment								
	Soil Flushing + Groundwater Extraction	Inject treated groundwater and/or potable water to infiltration trenches or wells to alter hydraulic gradients and flush contaminated groundwater towards extraction trenches/wells. Remove VOCs from extracted water using methods such as granular activated carbon (GAC) absorption or air stripping. Method can be enhanced by increasing subsurface permeability using technologies listed for soil such as soil mixing or fracturing.	Can effectively limit downgradient plume migration and provide short-term COC concentration decreases, but rapid aquifer restoration will not occur because a very high number of pore volumes must be flushed though the saturated zone and the rate of flushing is severely limited in some areas of Berkeley Lab by low permeability materials in the saturated zone. May result in undesirable mobilization of DNAPL.	This technology has been implemented as ICMs/pilot tests at a number of locations	Can effectively limit downgradient plume migration and may result in long-term decreases in COC concentrations in some areas, but rapid aquifer restoration is unlikely to occur because a very high number of pore volumes must be flushed though the saturated zone and the rate of flushing is severely limited in some areas of Berkeley Lab by low permeability materials in the saturated zone.	Implementable.	Can effectively limit downgradient plume migration, and may result in long-term decreases in COC concentrations in some areas, although the rate of flushing is severely limited in some areas of Berkeley Lab by low permeability materials in the saturated zone.	Implementable.	Retain for further consideration.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies (cont'd.)	Extraction with ex-situ treatment (cont'd.)								
	Dual-Phase Extraction (DPE)	Extract VOCs in vapor and groundwater simultaneously under vacuum through dual-phase extraction wells. Lowered water table increases treatment zone volume for vapor extraction, which generally removes contaminant mass more quickly than groundwater extraction. Remove VOCs from vapor stream with a vapor treatment system such as GAC absorption, and from groundwater stream using water treatment system, such as a GAC system.	This method is most effective in relatively high permeability/low moisture content soils where soil concentrations are high or DNAPL is present. Lowering of water table and simultaneous removal of soil VOCs is likely to result in lowering of groundwater concentrations. However, if DNAPLs or residual soil contamination remains below the lowered water table, MCSs may not be achievable.	Implementable. This technology has been implemented as an ICM in the core area of the B7 lobe of the Old Town plume.	Effectiveness at Building 53/58 slope DPE system in core of Building 7 lobe is poor because of low permeability/high moisture content soils and low contaminant concentrations in soil. Similar results are expected in other plume core areas.	Implementable.	Effectiveness is expected to be similar to plume core areas.	Implementable.	Retain for further consideration for plume source areas. Eliminate from further consideration based on effectiveness for plume core and periphery areas.
	Air Sparging	Compressed air, injected into lower portion of affected aquifer, percolates up through saturated zone causing transfer of VOCs from aqueous to vapor phase, vapors migrate to the vadose zone to be collected with a soil vapor extraction system.	Since sparging requires intimate contact of the air with the source solvents, it is not effective in heterogeneous, low permeability soils.	Would require a large number of wells. Potential mobilization of VOC vapors is a potential health concern.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on implementation and effectiveness.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies (cont'd.)	Extraction with ex-situ treatment (cont'd.)								
	In-Well Air Stripping	Air is injected into a double screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Once in the well, some of the VOCs in the contaminated ground water are transferred from the dissolved phase to the vapor phase by air bubbles. The contaminated air rises in the well to the water surface where vapors are drawn off and treated by a soil vapor extraction system.	Limited effectiveness in heterogeneous, low permeability saturated zone soils. Effectiveness is limited to the immediate area of the well.	Would require a large number of wells.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on effectiveness.
	Steam/hot water Injection	Steam or hot water is forced into an aquifer through injection wells to vaporize volatile contaminants. Vaporized components rise to the unsaturated zone where they are removed by vacuum extraction and then treated.	Limited effectiveness in heterogeneous, low permeability soils.	Potential mobilization of VOC vapors is a potential health concern.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on effectiveness.

Based on the screening matrices presented above, the following corrective measures alternatives were retained for further evaluation:

Soil

- No Action
- Institutional Controls
- Containment (Capping, Solidification, Stabilization)
- Chemical Oxidation
- Soil Vapor Extraction
- Thermally Enhanced SVE/DPE
- Soil Flushing (with water) + Groundwater Extraction
- Soil Mixing
- Excavation with offsite disposal.

Groundwater

- No Action
- Monitored Natural Attenuation (plume core and periphery zones)
- Institutional Controls
- Containment and Capture (slurry walls, sheet pile walls, grout curtains drains, trenches, extraction wells)
- Permeable Reactive Barrier and Funnel & Gate (plume periphery zones)
- Chemical Oxidation
- Enhanced Bioremediation (plume core and periphery zones)
- Soil Flushing (with water) + Groundwater Extraction
- Dual-Phase Extraction (source zone).

A discussion of the unit-specific applicability of each of these technologies is provided in the following section. As discussed in Section 4.1.1.4, a tiered approach to meeting risk-based and regulatory-based groundwater MCSs is likely to be implemented at Berkeley Lab, therefore the effectiveness of each alternative in meeting each of these MCSs in the plume source area, plume core area, and plume periphery area was addressed individually.

4.3. SITE-SPECIFIC SELECTION AND EVALUATION OF CORRECTIVE MEASURES ALTERNATIVES FOR VOLATILE ORGANIC COMPOUNDS (VOCs) IN SOIL AND GROUNDWATER

This section describes the site-specific factors that affect the evaluation and selection of corrective measures alternatives, and includes discussions of the distribution of COCs, results of the human health risk assessment, concentration trends, previously implemented ICMs, and results of bench-scale and field-scale pilot tests. The data and other information presented in this section are derived primarily from the Draft Final RFI Report (Berkeley Lab, 2000a), Environmental Restoration Program Quarterly Progress Reports, and the Human Health Risk Assessment (Berkeley Lab, 2003a).

4.3.1. Building 51/64 Groundwater Solvent Plume

The Building 51/64 Groundwater Solvent Plume is located in the Bevalac Area of Berkeley Lab, which primarily includes the Building 51/64 complex (the decommissioned Bevatron particle accelerator and support facilities) and the Building 71 complex (the decommissioned Super Heavy Ion Linear Accelerator [Super HILAC]). Major development of the area began in the early 1950s, when construction started on the Bevatron and associated support facilities. The Bevatron operated for almost 40 years from 1954 to 1993.

The plume extends westward from the southeast corner of Building 64 (**Figure 4.3.1-1**). The principal plume constituents are halogenated VOCs that were used as cleaning solvents, including 1,1,1-TCA, TCE, PCE, and their associated degradation products (e.g., 1,1-DCE, 1,1-DCA, cis-1,2-DCE, and vinyl chloride). The principal source of the plume was likely the Building 51/64 Former Temporary Equipment Storage Area (AOC 9-12), although other sources in the Building 51/64 area may have contributed to the plume.

Contaminated source area soils were excavated as an ICM in August 2000 and a groundwater extraction system was installed in the backfilled excavation. In addition, an in situ soil flushing pilot test is being conducted in the source area to evaluate the implementability of the method and its potential effectiveness in achieving MCSs. Contaminated groundwater in the vicinity of Building 51 has the potential to enter the building's subdrains, which originally were

routed to the stormdrain system that discharges to North Fork Strawberry Creek. To avert discharges to the creek, an ICM was implemented in 1996 that routes water from the Building 51 subdrain system to a groundwater treatment system. The treated groundwater is then discharged to the sanitary sewer. The locations of the ICMs and pilot test are shown on **Figure 4.3.1-1**.

4.3.1.1. Current Conditions

Geology and Hydrogeology

The area of the Building 51/64 plume is underlain by sedimentary rocks of the Orinda Formation, which consist primarily of siltstones and fine-grained sandstones that strike approximately east-west and dip 25° to 60° to the north. The bedrock is overlain by a thin veneer of artificial fill that thickens substantially to the southwest towards the former location of Blackberry Canyon, a major east-west-trending drainage course that bisected the current Building 51/64 area prior to development. Artificial fill, in places greater than 100 feet thick, was placed in the drainages in the Bevalac area, and the ridges were cut by up to 40 feet to provide graded areas on which to construct buildings and parking lots.

The water table in the Building 51/64 Plume Area lies primarily within the Orinda Formation east of Building 51B, but is within the artificial fill to the west. Slug tests and pumping tests conducted on wells screened in the Orinda Formation in the Building 51/64 plume area indicate hydraulic conductivity values ranging from approximately 2×10^{-9} to 3×10^{-8} meters per second.

To the southwest of Building 64, the contact between artificial fill in Blackberry Canyon and the Orinda Formation cuts down across the water table. **Figure 4.3.1-2** shows the intersection between the water table and the predevelopment topographic surface, illustrating the area in which the water table lies within the artificial fill. Slug test data in this area indicate relatively high hydraulic conductivities for the artificial fill (typically 10^{-7} to 10^{-6} meters per second). Groundwater wells generally yield less than 200 gpd from wells screened solely in the Orinda Formation and have short-term yields greater than 200 gpd from wells screened wholly or partly in the artificial fill or colluvium (**Figure 4.3.1-2**).

The water level elevation contour map for the Bevalac Area is shown on **Figure 4.3.1-3**, and indicates that flow is approximately southwestwards. The map contours indicate that the horizontal component of the hydraulic gradient (dh/dl) is approximately 0.4 near Building 64. Assuming a hydraulic conductivity (K) of 1×10^{-8} meters per second, which is typical of the Orinda Formation in this area and an effective porosity (n_e) of approximately 0.2, Darcy's law ($v_x = K/n_e \times dh/dl$) results indicates an average linear groundwater velocity (v_x) of 0.6 meters per year (2 feet per year). For flow in the artificial fill, groundwater velocities would be expected to be approximately an order of magnitude greater.

Groundwater Contamination

The Building 51/64 plume contains a number of halogenated non-aromatic VOCs, most of which have been detected at concentrations above MCLs. The maximum concentrations of chemicals detected at concentrations above MCLs in FY03 are listed in **Table 4.3.1-1**, and are compared to the target risk-based MCSs. PCE, carbon tetrachloride, 1,1-DCA, and vinyl chloride were detected in the groundwater at concentrations above target risk-based MCSs in FY03.

Table 4.3.1-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 51/64 Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Regulatory-Based Groundwater MCS (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
TCE	1,590	5	1,594
PCE	692	5	343
carbon tetrachloride	40.6	0.5	27
cis-1,2-DCE	226	6	98,405
trans-1,2-DCE	25	10	94,405
1,1-DCE	2,210	6	28,873
methylene chloride	57.2	5	10,381
1,1-DCA	15,800	5	3,663
1,2-DCA	24.5	0.5	1,030
vinyl chloride	835	0.5	12
1,1,1-TCA	277	200	1,570,783
1,1,2-TCA	11.1	5	1,905

Note: Boldface concentration indicates that the maximum detected concentration of the COC in FY03 exceeds the target risk-based groundwater MCS.

Groundwater COC Trends

Before implementation of the source area ICM, halogenated VOCs were detected at total concentrations above 100,000 µg/L in groundwater samples collected in the source area, with 1,1,1-TCA comprising approximately 90% of the contaminant mass. The source area was excavated as an ICM and backfilled with gravel in 2000. Subsequent to the ICM, halogenated non-aromatic VOC concentrations have decreased to a total concentration of approximately 500 µg/L or less in the source area, with the primary COC detected 1,1-DCA.

Concentration trends for total halogenated non-aromatic VOCs in the Building 51/64 plume are shown on **Figure 4.3.1-4a**, **Figure 4.3.1-4b**, and **Figure 4.3.1-5**. Concentrations of VOCs detected in MW51-96-18, SB64-98-17, and SB64-98-8 near the plume source area have decreased significantly since the ICM was implemented. There has also been a decreasing trend in the concentrations of VOCs detected in MW51-96-16, in the plume core. Except for a decrease in the concentration of vinyl chloride in MW56-98-2, concentrations of VOCs detected in other wells monitoring the plume have remained relatively constant.

Most of the plume constituents comprise chemicals that represent primary or intermediate compounds in the PCE or 1,1,1-TCA degradation pathway. The relative proportions of plume constituents differ substantially with distance downgradient from the source area. The primary COC prior to the ICM (1,1,1-TCA) is generally detected only in the source area, with its daughter product, 1,1-DCA detected in the source area and also in downgradient areas.

A similar pattern is also observed for PCE and its daughter products. Well MW51-96-18, which is located close to the source area, contains a higher fraction of PCE and TCE and a lower fraction of DCE and vinyl chloride (**Figure 4.3.1-6**) than core area well MW51-96-16 (**Figure 4.3.1-7**), located about 100 feet downgradient from the source area. Well MW51-00-8, located in the downgradient area, contains only degradation products with no PCE or TCE (**Figure 4.3.1-8**). These three wells show consistent temporal trends in daughter/parent ratios. The source area well (MW51-96-16) shows an increase in the relative proportion of parent products through time, accompanied by a substantial decrease in concentrations (**Figure 4.3.1-6**). This appears to indicate that the rate of degradation is slower than the rate of advection of COCs derived from desorption of residual soil COCs into the plume. Proportions of parent/daughter products have remained relatively constant in

the mid-plume well MW51-96-16) (**Figure 4.3.1-7**) indicating that equilibrium has been reached between advection of COCs and degradation. The downgradient well (MW51-00-8) has shown a relatively constant proportion of vinyl chloride to DCE over time, with the total concentration of VOCs also remaining relatively constant (**Figure 4.3.1-8**). This suggests that equilibrium has been reached between advection of COCs and degradation in the downgradient area. Since concentrations of COCs in the groundwater in the source area have been significantly reduced, the advection of COCs into the core and downgradient areas should decline over time.

Soil Contamination

The primary VOCs detected in soil samples collected in the source zone for the Building 51/64 Plume were 1,1,1-TCA, TCE, 1,1-DCA, and PCE. Relatively high concentrations of VOCs (i.e., maximum concentrations of 1,1,1-TCA and PCE were 2,800 mg/kg and 680 mg/kg, respectively) were detected in soil samples collected from the excavated plume source area prior to the ICM, with several COCs above target risk-based MCSs. Residual VOC concentrations, however, are relatively low (0.23 mg/kg total VOCs maximum).

Maximum concentrations of COCs detected in residual soil are listed in **Table 4.3.1-2**. All concentrations are below both target risk-based MCSs and regulatory-based MCSs (for protection of groundwater).

Evidence of DNAPL and Residual Soil Contamination

Prior to the ICM, the concentrations of 1,1,1-TCA and PCE detected in the Building 51/64 plume source area exceeded their soil saturation concentrations, indicating that free DNAPLs were probably present. However, post-ICM soil sample concentrations were substantially below those levels. Similarly, although concentrations of both carbon tetrachloride and 1,1,1-TCA in groundwater exceeded 1% of their solubilities and effective volubilities prior to the ICM, post-ICM concentrations were substantially below those levels. These comparisons provide evidence for past, but not current presence of DNAPLs.

Table 4.3.1-2. Maximum Concentrations of COCs Detected in Residual Soil in the Building 51/64 Groundwater Solvent Plume Source Area

COC	Maximum Concentration Detected (mg/kg)	Target Risk-Based Soil MCS (mg/kg)	Regulatory-Based Soil MCS ^(a) (mg/kg)
PCE	0.16	0.45	0.7
TCE	0.085	2.3	0.46
cis-1,2-DCE	0.022	38	0.19
1,1,1-TCA	0.11	690	7.8
1,1-DCA	0.047	1.3	0.2
1,1-DCE	0.006	8	1.0

(a) MCS for the protection of beneficial uses of groundwater.

4.3.1.2. Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 51/64 Groundwater Solvent Plume:

- Residual soil contamination is not present at concentrations that exceed either regulatory-based or target risk-based MCSs. However, soil containing high concentrations of COCs indicative of free DNAPLs was present prior to the source area soil excavation ICM. The potential for leaching and dissolution of COCs from soil in the source area was substantially reduced as a result of the ICM.
- Groundwater COC concentrations have generally shown gradual long-term declines over most of the plume area. A substantial decline in concentrations was observed in the ICM excavation area and immediately downgradient in post-ICM groundwater samples.
- Groundwater in the source area flows primarily through relatively low permeability rocks of the Orinda Formation. The estimated groundwater velocity is approximately 2 to 20 feet per year.
- Groundwater yields are less than 200 gpd from upgradient and source area wells where the contamination is in the Orinda Formation. Target risk-based MCSs are applicable to this area. Groundwater yields are greater than 200 gpd from downgradient wells where the contamination is in the artificial fill and colluvium. Regulatory-based MCSs are applicable to this area.
- Spatial variations in plume chemistry and two studies on the potential for biodegradation indicate that biodegradation has been occurring throughout the Building 51/64 plume. The lack of a temporal change in the relative proportions of COCs in the central plume area indicates that a relative state of equilibrium has been reached between degradation of dissolved COCs in this area and desorption and downgradient migration of COCs from the source area.

- Migration of COCs beyond the downgradient boundary of the plume does not appear to be occurring, with the downgradient limit of detectable COCs remaining static. Migration of COCs to North Fork Strawberry Creek via the Building 51 subdrain system is not occurring because water from the subdrain is conveyed to a treatment system then discharged to the sanitary sewer.
- Concentrations of COCs exceed target risk-based MCSs in groundwater near the source area, and vinyl chloride slightly exceeds target risk-based MCSs in the central part of the plume. The potential human receptor and risk-based exposure pathway of potential concern is exposure to COCs by a hypothetical future indoor worker breathing vapor migrating from the groundwater to indoor air (Berkeley Lab, 2003a).
- Concentrations of COCs throughout most of the plume exceed regulatory-based MCSs. However, regulatory-based MCSs are only applicable to the downgradient portion of the plume, where the water table is in the fill.

4.3.1.3. *Evaluation of Retained Corrective Measures Alternatives*

Concentrations of soil COCs in the Building 51/64 plume source area are less than both target risk-based and regulatory-based MCSs. Concentrations of several groundwater COCs exceed target risk-based MCSs in the plume source area beneath the southeast corner of Building 64. In addition, the concentration of vinyl chloride slightly exceeds target risk-based MCS in the central portion of the plume. Regulatory-based MCSs are not applicable to the source area of the plume, and the area immediately downgradient from the source area, since well yields are less than 200 gpd. However regulatory-based MCSs are probably applicable to the downgradient area of the plume, beneath and northwest of Building 51B. No migration of COCs is occurring beyond the plume margins, so migration control is not a concern.

The corrective measures alternatives that are evaluated for the Building 51/64 Groundwater Solvent Plume are those that were retained in **Table 4.2.3-1** and **Table 4.2.3-2** (for soil and groundwater, respectively). The results of the evaluation are provided in **Table 4.3.1-3** and discussed below.

No Action

No action for the Building 51/64 Groundwater Solvent Plume would consist of terminating all groundwater monitoring activities, stopping of the ongoing Building 64 soil flushing pilot test and groundwater extraction from the gravel-filled ICM excavation, and

Table 4.3.1-3. Evaluation of Corrective Measures Alternatives, Building 51/64 Groundwater Solvent Plume

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (c)	Regulatory Agency Acceptance	Community Concerns
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	yes	yes	4	3	2	4	1	1
Institutional Controls	yes/no	no	no	yes	2	1	3	4	2	2
Groundwater Containment/Capture	no/yes	no	yes	yes	2	2	2	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/yes	no	yes	yes	2	2	2	3	4	3
Chemical Oxidation	no/no	no	no	yes	2	2	2	2	5	5
Soil Vapor Extraction	no/no	no	no	yes	1	1	1	3	3	3
Thermally Enhanced SVE/DPE	no/no	no	no	yes	1	1	1	3	3	3
Enhanced bioremediation	yes/yes	yes	yes	yes	4	4	2	4	4	4
Soil Flushing and Groundwater Extraction	yes/no	yes	unknown	yes	3	3	4	3	4	4
Soil Mixing	yes/yes	yes	no	yes	3	3	4	5	3	3
Excavation with Offsite Disposal	yes/no	yes	yes	yes	4	4	4	4	4	4

(a) Level of Compliance Ranking

1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance

1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

allowing water in the Building 51 subdrain system to flow through the stormdrain system to North Fork Strawberry Creek. Concentrations of COCs in the groundwater would likely remain at levels greater than both target risk-based MCSs and regulatory-based MCSs, for the foreseeable future. These conditions would require establishment of Institutional Controls in order to protect future workers, and/or to designate groundwater as a non-drinking water source. In addition, this alternative would likely be unacceptable to the regulatory agencies and the community. The No Action alternative is not protective of human health and the environment and is therefore eliminated from further consideration.

Monitored Natural Attenuation

Studies of chemical (i.e., specific electron acceptors and metabolic byproducts) and biological parameters applicable to the potential for biodegradation of the Building 51/64 plume were conducted in both 1997 and 2003. Both studies concluded that the potential for biodegradation within the plume was high. A report discussing the results of the 2003 investigation is contained in **Appendix E**. In addition, concentrations of VOCs in the groundwater in the source area have been significantly reduced since the source area soil excavation ICM was completed. The lines of evidence that demonstrate that MNA would be an effective alternative for remediation of the Building 51/64 Groundwater Solvent Plume are as follows:

1. The source area has been removed.
2. The contaminants are biodegradable.
3. The plume is stable.
4. Biodegradation daughter products are present and increase in proportion downgradient from the source area.
5. Bacteria capable of degrading chlorinated solvents were identified as being present in the plume.
6. Isotopic analysis of parent and daughter products indicates that biodegradation is occurring and vinyl chloride is being converted to ethane.
7. pH, moisture, and organic carbon content are sufficient to support natural biodegradation.
8. Culturable bacteria densities indicated that microbial activity was normal and high enough to support significant biodegradation activity.

MNA is therefore the recommended alternative for the Building 51/64 Groundwater Solvent Plume. However, relatively high concentrations of halogenated VOCs still remain in the groundwater adjacent to the excavated source area. The effectiveness of MNA and the length of time required to attain the required MCSs may be significantly improved if this area were first isolated from the remainder of the plume and/or concentrations of COCs in groundwater in the source area are reduced. More aggressive remediation technologies are therefore recommended for the source area in combination with MNA, as described below.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The groundwater plume is stable so no containment or capture of the plume boundary is currently required or planned. However, containment of COCs in the source area of the plume would likely allow MNA to result in decreasing COC concentrations in downgradient areas. Therefore, containment of the source area using a groundwater extraction trench, or groundwater extraction wells, is a recommended alternative for the plume when used in conjunction with another method such as MNA.

An ICM that captures and treats water in the Building 51 subdrain system was installed to prevent COCs from flowing through the stormdrain system to North Fork Strawberry Creek. Continuing capture and treatment is required as a regulatory compliance measure until discharge to surface water is shown to be below detectable levels.

Permeable Reactive Barrier/Funnel and Gate

A permeable reactive barrier or funnel and gate system would serve a similar function to a groundwater capture system, and therefore could be applicable to source containment.

Therefore, this method could be used to minimize migration of COCs from the source area to downgradient areas, and is considered to be a recommended alternative when used in conjunction with MNA.

Chemical Oxidation

The effectiveness of chemical oxidation for remediation of the source area of the plume is not known and would require pilot testing prior to any full-scale implementation. In situ chemical oxidation is generally not effective in low permeability materials such as the Orinda Formation. As described in Section 4.3.2, pilot testing of this technology in the low permeability Building 51L Groundwater Solvent Plume source area was not effective, so this method is unlikely to be effective for the Building 51/64 plume, and is therefore not recommended.

Soil Vapor Extraction (SVE) and Thermally Enhanced Dual Phase Extraction (DPE)

The effectiveness of soil vapor extraction (SVE) systems is controlled by both contaminant volatility and subsurface vapor flow. The COCs detected at the Building 51/64 plume are highly volatile and can be easily removed from soil and groundwater if sufficient vapor flow through the soil can be established. Thermal heating, in combination with dewatering, dries the soil, thereby increasing the effectiveness of an SVE system. However, the method is not effective in low permeability materials (such as the Orinda Formation in the Building 51/64 area), which still retain excess moisture even with soil drying. In addition, due to the high capital and operating cost of treating a small area such as the Building 51/64 plume source area, this alternative is not recommended.

Soil Mixing

Since the remaining soil COCs at the Building 51/64 Plume source area lie beneath Building 51/64, soil mixing is not implementable at this unit. In addition, the shallow depth of soil contamination would lend itself readily to soil excavation for a similar cost to soil mixing, with a much greater potential effectiveness. Soil mixing is therefore not recommended.

Enhanced Bioremediation

Available data indicate that natural biodegradation of COCs is occurring within the Building 51/64 plume, and that enhancement could potentially interfere with the naturally occurring degradation processes. In addition, the relatively high dissolved oxygen (DO) concentrations in the plume core area indicate that the application of HRC® would not be an effective alternative. An additional concern with the use of HRC is that concentrations of metals dissolved in the groundwater can increase significantly due to the lowered pH. Enhanced bioremediation is therefore not recommended for consideration.

Soil Flushing and Groundwater Extraction

A soil flushing pilot test, consisting of a groundwater injection trench inside Building 64 and a groundwater extraction trench east of the building was initiated in the plume source zone in October 2003. The test was designed to target an inclined, relatively high permeability zone, which appeared to be a migration pathway for groundwater COCs. Although insufficient time has elapsed to assess the long-term effectiveness of the pilot test, initial data indicate that the method has been effective and that COCs are being mobilized toward the extraction trench. However, to increase the effectiveness of the test and reduce the potential for mobilization of COCs to the southwest of the test area, an additional extraction trench located downgradient from the injection trench is recommended.

Excavation with Offsite Disposal

Based on available sampling data, residual soil concentrations are below both target risk-based and regulatory-based MCSs. The highest concentrations of soil COCs are likely located at shallow depths under the southeast end of Building 64, where the residual COCs sorbed to soil are likely present due to equilibrium partitioning with the dissolved phase. The highest concentrations of groundwater contaminants are also present at shallow depths under the southeast corner of the building. Since Building 64 overlies the source area, excavation is not currently possible, but should be considered if the building were to be removed.

Summary of Building 51/64 Plume Corrective Measures Implementation Strategy

The remediation objectives for the Building 51/64 Plume are to: 1) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs do not migrate into areas where concentrations are less than MCLs; 2) reduce groundwater COCs concentrations in the source area below target risk-based MCSs; 3) reduce vinyl chloride concentrations in the area near Building 51B area to below the target risk-based MCS; 4) reduce groundwater COC concentrations in the downgradient area where well yields exceed 200 gpd to below regulatory-based MCSs; and, 5) ensure that groundwater COCs at detectable concentrations do not migrate to surface water through the storm drain system.

The pilot test results indicate that soil flushing may be effective in meeting remediation objective (2), reducing groundwater COC concentrations in the source area to below target risk-based MCSs. The pilot test would be continued as the proposed corrective measure; however, it would be enhanced with an additional groundwater collection trench extending along the south side of Building 64. This collection trench would both reduce the potential for hydraulic head changes caused by soil flushing to increase groundwater advection rates, and reduce the potential for COCs at concentrations above regulatory-based MCSs to migrate from the source area to downgradient areas (remediation objective [1]). Although a permeable reactive barrier or funnel and gate system could also reduce migration of COCs, it would not be effective in controlling hydraulic head changes caused by source area soil flushing, and so is not recommended. Excavation of source area soils would also be effective in meeting remediation objectives (1) and (2), but it should be considered only if Building 64 were to be removed.

Given that MNA has been documented to be a viable corrective measure for the plume, remediation objectives (1), (3), and (4) are likely to be met by MNA, as long as containment and remediation of the source zone is conducted, as described above.

Objective (5) should be met by continued capture and treatment of groundwater in the Building 51 subdrain system until it can be shown that COC concentrations at the point of compliance (the outfall to the creek) are below detectable levels.

4.3.2. Building 51L Groundwater Solvent Plume and Source Area

The Building 51L Groundwater Solvent Plume is centered near the southwest corner of Building 51L in the Bevalac Area of Berkeley Lab (**Figure 4.3.2-1**). The Bevalac Area is described in Section 4.3.1.

Building 51L was constructed in the early 1980's as a computer support facility for Bevatron operations. In the early 1990's, Building 51L was reconfigured for use as a computer training facility. The use of the building for conducting training classes was terminated at the end of 2003, and the building was demolished in March 2004 as part of the Bevatron decommissioning process. A machine/maintenance shop was located in the Building 51L area prior to the 1970's. Solvent drum racks were reportedly located at various times at the current Building 51L location, along the adjacent wall of Building 51A, and along a former retaining wall located approximately 20 feet west of Building 51L.

The principal plume constituents are halogenated VOCs that were used as cleaning solvents, including TCE, PCE, and associated degradation products (e.g., cis-1,2-DCE, trans-1,2-DCE, and vinyl chloride). Based on the results of soil and groundwater sampling, solvent spills that occurred at the location of Building 51L appear to be the primary source for the soil and groundwater contamination.

4.3.2.1 Current Conditions

Geology and Hydrogeology

Building 51L was constructed on artificial fill that lies within a former hillside swale (**Figure 4.3.2-2**). The locations of soil borings, groundwater monitoring wells, and temporary groundwater sampling points in the Building 51L area are shown on **Figure 4.3.2-3**. An east-west geologic cross section (A-A') immediately south of Building 51L is shown on **Figure 4.3.2-4**. The artificial fill underlying the Building 51L area consists of gravelly clay and sandy or clayey silt. The thickness of the fill increases from approximately 10 to 20 feet at the retaining wall west of Building 51L to 30 feet to the northeast of the building. The artificial fill overlies residual soil/colluvium consisting primarily of silty clay with some gravel that ranges from approximately 5

to 20 feet thick. Underlying the soil/colluvium is shale and siltstone of the Great Valley Group. The three geologic units (fill, soil/colluvium, and bedrock) beneath the site act as distinct hydrogeologic units.

Groundwater is extracted from two wells south of the former location of Building 51L as an ICM. Groundwater extraction has resulted in drawdown of the water table to depths as great as 20 to 35 feet bgs near the extraction wells. In the absence of groundwater extraction, the water table would be between approximately 13 and 15 feet bgs in this area.

Based on laboratory-wide slug tests, the hydraulic conductivity ranges from 10^{-5} to 10^{-7} meter per second for colluvium/alluvium, 10^{-5} to 10^{-8} meters per second for the Great Valley Group, and 10^{-6} to 10^{-8} meters per second for artificial fill. Based on the performance of the extraction wells, the long-term sustainable yield from the Great Valley Group bedrock in this area is less than 200 gpd. Groundwater yields measured in wells screened in the fill above the bedrock in the Building 51L area are also less than 200 gpd.

The water level elevation contour map for the Bevalac Area is shown on **Figure 4.3.1-3**, and indicates that regional flow is northward near Building 51L. The gradient has been locally modified by groundwater extraction at the south end of the building. On the west side of Building 51L, the gradient in the artificial fill appears to be directed toward the stormdrain backfill and/or storm drain catch basin.

The groundwater elevation map contours indicate that the horizontal component of the hydraulic gradient (dh/dl) is approximately 0.3 near Building 51L. Assuming a hydraulic conductivity (K) of 1×10^{-7} meters per second, which is typical of artificial fill and an effective porosity (n_e) of approximately 0.2, Darcy's law ($v_x = K/n_e \times dh/dl$) results indicates an average linear groundwater velocity (v_x) of 4.5 meters per year (15 feet per year).

Groundwater Contamination

The Building 51L Groundwater Solvent Plume contains a number of halogenated non-aromatic VOCs, most of which have been detected at concentrations above MCLs (**Table 4.3.2-1**). The maximum concentrations of chemicals detected at concentrations above MCLs in FY03

are listed in **Table 4.3.2-1**, and are compared to the target risk-based MCSs. Vinyl chloride was detected at concentrations exceeding the target risk-based MCS.

The highest total VOC concentrations in groundwater are present in a northwest-trending zone (**Figure 4.3.2-5**) whose west edge lies close to the active stormdrain west of Building 51L (Berkeley Lab, 2002c). The area in which the maximum concentrations of primary solvent products (i.e., PCE and TCE) in groundwater have been detected is apparently offset to the northeast of the locus of maximum concentrations of daughter (degradation) products (cis-1,2-DCE, trans-1,2-DCE, and vinyl chloride). This suggests either that groundwater flow has generally been directed westward toward the stormdrain or that conditions favorable for degradation occur to the west (Berkeley Lab, 2002c).

Table 4.3.2-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 51L Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
carbon tetrachloride	2.7	0.5	27
1,1-DCA	245	5	3,663
1,1-DCE	71	6	1,030
cis-1,2-DCE	1,100	6	98,405
trans-1,2-DCE	469	10	94,405
PCE	40	5	343
TCE	1,373	5	1,594
vinyl chloride	542	0.5	12

Note: boldface concentration indicates that the maximum detected concentration of the COC in FY03 exceeds the target risk-based groundwater MCS.

The plume covers a relatively small area approximately 100 feet wide by 70 feet long centered under the southwest corner of Building 51L (**Figure 4.3.2-5**). Groundwater contaminants have generally not been detected in wells screened in bedrock, indicating that the vertical extent of groundwater contamination is limited to the overlying fill and colluvium.

Groundwater COC Trends

Concentrations of the individual halogenated VOCs detected in temporary groundwater sampling points SB51L-98-1A and SB51L-02-3 located near the southwest corner of Building 51L have been increasing (**Figure 4.3.2-6**). The increases in concentrations appear to be related to groundwater extraction from EW51L-00-1, located approximately 10 to 15 feet from the sampling points.

Soil Contamination

Maximum concentrations of COCs detected in the soil in the source area of the Building 51L Groundwater Solvent Plume are listed in **Table 4.3.2-2**. The concentrations of soil COCs are less than the target risk-based MCSs, except for PCE, TCE, chloroform and vinyl chloride. However, the detection frequency of chloroform and vinyl chloride was less than 1% so the inclusion of these analytes as COCs is considered to be a statistical artifact, and not to represent risks to human health. The maximum concentrations of PCE and TCE were detected under Building 51L, at approximately 6.5 to 12 feet below the building (**Figure 4.3.2-7**). PCE was either the primary contaminant detected or it was detected at approximately the same concentration as TCE in this area. At almost all other locations, TCE was the primary contaminant detected. Total concentrations of VOCs above 1 mg/kg extend to a maximum depth of approximately 20 feet. The contamination is restricted primarily to the fill and underlying colluvium.

Table 4.3.2-2. Maximum Concentrations of COCs Detected in Soil in the Building 51L Groundwater Solvent Plume

COC	Maximum Concentration Detected (mg/kg)	Target Risk-Based Soil MCS (mg/kg)
PCE	21	0.45
TCE	24	2.3
1,1,1-TCA	0.019	690
1,1-DCA	0.8	1.3
1,1-DCE	0.074	7.9
benzene	0.0053	0.1
chloroform	0.31	0.28
cis-1,2-DCE	3.1	38
trans-1,2-DCE	0.45	50
vinyl chloride	0.012	0.0035

Note: boldface concentration indicates that the concentration exceeds the target risk-based soil MCS.

Evidence of DNAPL

Since the maximum concentrations of COCs detected in the soil are substantially lower than their soil saturation concentrations, the soil data provide no evidence for the presence of DNAPL. Similarly, concentrations of COCs in groundwater are low relative to their solubilities and effective volubilities, again providing no evidence for the presence of DNAPL.

4.3.2.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 51L Groundwater Solvent Plume and source area:

- No evidence is available suggesting the presence of free-phase DNAPL in soil or groundwater.
- Soil and groundwater contamination is limited to the upper 20 to 25 feet in the artificial fill and colluvium.
- Artificial fill and colluvium/residual soil beneath the Building 51L area have relatively low permeabilities. Groundwater wells screened in these units yield less than 200 gpd. In addition, based on the performance of the groundwater extraction wells, the long-term sustainable yield from the underlying Great Valley Group bedrock in this area is less than 200 gpd. Target risk-based MCSs are therefore applicable.
- The COCs appear to have undergone some natural biodegradation. Byproducts of PCE and TCE degradation, including cis-1,2 DCE and vinyl chloride have been detected in the soil and groundwater.
- Vinyl chloride is the only COC that exceeds the target risk-based MCS for groundwater. PCE and TCE concentrations exceed the target risk-based MCSs for soil. The potential human receptor and risk-based exposure pathway of potential concern is exposure to COCs by a hypothetical future indoor worker breathing vapor migrating from the groundwater or from soil to indoor air (Berkeley Lab, 2003a).
- Migration of COCs beyond the downgradient boundary of the plume does not appear to be occurring, with the downgradient limit of detectable COCs remaining static.

4.3.2.3 Evaluation of Retained Corrective Measures Alternatives

Concentrations of both soil and groundwater COCs in the Building 51L plume and source area exceed target risk-based MCSs. Regulatory-based MCSs are not applicable. Available data

indicate that DNAPLs are not present. No migration of COCs is occurring beyond the plume margins, so migration control is not a concern. Transfer of COCs to surface water could potentially occur through the storm drain system, if the groundwater level were not maintained beneath the base of the storm drain by pumping. However, as a result of dilution and volatilization of COCs, the chemical concentrations should be below detectable levels at the outflow to the creek, as shown by the absence of detectable Building 51L plume COCs in surface water samples collected from North Fork Strawberry Creek prior to groundwater extraction.

The corrective measures alternatives that are evaluated for the Building 51L Groundwater Solvent Plume and source area are those that were retained in **Table 4.2.3-1** and **Table 4.2.3-2** (for soil and groundwater, respectively). The results of the evaluation are provided in **Table 4.3.2-3** and discussed below.

No Action

No action for the Building 51L Groundwater Solvent Plume would consist of termination of all groundwater monitoring activities and stopping of extraction and treatment of groundwater. Under this alternative, once extraction was halted, contaminated groundwater could enter the storm drain system and then flow into North Fork Strawberry Creek, although as described above, the COC concentrations would likely remain below levels of concern at the creek outfall. Since there is no evidence that COC concentrations are declining, groundwater concentrations would likely remain above target risk-based MCSs for the foreseeable future. These conditions would require establishment of Institutional Controls to protect future workers. In addition, this alternative would likely be unacceptable to the regulatory agencies and the community. The No Action alternative is not protective of human health and the environment and is therefore eliminated from further consideration.

Table 4.3.2-3. Evaluation of Corrective Measures Alternatives, Building 51L Groundwater Solvent Plume and Source Area

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (c)	Regulatory Agency Acceptance	Community Concerns
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	no/no	no	no	yes	1	1	1	4	1	1
Institutional Controls	yes/no	no	no	yes	2	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	yes	Yes	3	2	3	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/no	no	no	yes	1	1	1	3	4	3
Chemical Oxidation	no/no	unknown	yes	yes	1	1	2	3	5	5
Enhanced bioremediation	yes/yes	unknown	yes	yes	2	2	2	3	4	4
Soil Flushing and Groundwater Capture	yes/yes	yes	yes	yes	3	3	2	4	4	4
Thermally Enhanced Dual Phase Extraction	yes/yes	unknown	yes	yes	1	3	1	2	5	5
Soil Mixing	yes/yes	yes	Yes	yes	3	3	3	2	4	4
Excavation and Offsite Disposal	yes/yes	yes	yes	yes	5	5	5	3	5	4

(a) Level of Compliance Ranking

1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance

1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997, including the Building 51L plume area. Geochemical parameters measured in well MW51-97-16, located near the core of the plume indicated conditions favorable for natural degradation processes. In particular, the dissolved oxygen concentration was very low (0.13 mg/L), nitrate and nitrite were not detected, manganese (Mn^{2+}) concentrations were low, and ferrous iron (Fe^{2+}) was present. These are favorable redox conditions under which reductive dechlorination of PCE and TCE by microorganisms can occur.

MNA, however, is considered not to be a potentially effective alternative under current plume conditions based on the relatively stable COC concentrations observed in the groundwater over the past several years. These observations indicate that MNA would not be an effective alternative unless the source area is first isolated from the remainder of the plume and/or concentrations of COCs in groundwater in the source area are significantly reduced. Therefore, MNA should only be considered in combination with more aggressive remediation technologies.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The groundwater plume is stable, so no containment or capture of the plume boundary is currently required or planned.

An ICM consisting of a temporary groundwater pump-and-treat system was installed to lower the groundwater table and prevent infiltration of impacted groundwater into the storm drain system, and subsequent migration to surface water (North Fork Strawberry Creek). Continuing capture and treatment is required as a regulatory compliance measure until discharge to surface water

is shown to be below detectable levels. Lining or rerouting the storm drain line so that it does not traverse the plume area is recommended to achieve this objective and would allow discontinuing of groundwater capture.

Permeable Reactive Barrier/Funnel and Gate

The groundwater plume is stable, so rates of advection are low, so a permeable reactive barrier or funnel and gate system is not required to capture the plume boundary or control releases from the plume core area.

Chemical Oxidation

An in situ chemical oxidation pilot test was completed in the Building 51L Groundwater Solvent Plume source area in 2002. The purpose of the test was to determine the implementability and effectiveness of chemical oxidation to treat impacted groundwater at the unit. The report describing the test methodology and results is included in **Appendix B**. The test consisted of the injection of hydrogen peroxide (H₂O₂), combined with citric acid. Subsequent monitoring in nearby observation wells (e.g., **Figure 4.3.2-8** showing results for SB51L-03-1) indicated that the effect of chemical oxidation on contaminant levels was immediate, but short lived. Concentration levels rebounded quickly exceeding baseline and historical levels within a month in some cases (i.e., cis-1,2-DCE, **Figure 4.3.2-8**). Based on the results of the pilot test, chemical oxidation is not a recommended alternative.

Enhanced Bioremediation

A pilot test would need to be performed to evaluate the feasibility of enhanced bioremediation. However, because enhanced bioremediation requires the delivery of the enhancing agent to the source solvents, it is generally not effective in low permeability materials such as the fill/colluvium where the COCs are present at the unit, and is therefore not recommended.

Soil Flushing and Groundwater Extraction

Soil flushing using injection trenches constructed in the unsaturated zone could be used to flush contaminants from the vadose zone into the underlying saturated zone where

contaminants could be pumped and treated. This alternative is not recommended, however because the low permeability of the artificial fill, where most of the soil contamination is present, and the heterogeneous nature of the fill and colluvium limit the effectiveness of the method.

Soil Vapor Extraction (SVE) and Thermally Enhanced Dual Phase Extraction (DPE)

The effectiveness of SVE systems is controlled by both contaminant volatility and subsurface vapor flow. The COCs detected at the Building 51L plume are highly volatile and can be easily removed from soil and groundwater if sufficient vapor flow through the soil can be established. Thermal heating, in combination with dewatering, dries the soil, thereby increasing the effectiveness of an SVE system. However, the method is not effective in low permeability materials (such as the silt and clay material comprising the artificial fill at Building 51L), which still retain sufficient moisture even with soil drying. In addition, due to the high capital and operating cost of treating such a small area as the Building 51L plume, this alternative is not recommended.

Soil Mixing

Soil mixing is an implementable technology for the plume source area, but the effectiveness of this technology is not known. Excavation is preferred to soil mixing since excavation would be effective, and the cost of soil mixing would be higher than the costs of excavation, given the small source area and the need for pilot testing soil mixing prior to implementation. Soil mixing is therefore not recommended.

Excavation and Offsite Soil Disposal

Concentrations of both soil and groundwater COCs are above target risk-based MCSs. The highest concentrations of COCs are present at relatively shallow depths (approximately 20 to 25 feet bgs maximum) beneath the area where the southwest end of Building 51L was formerly located. Since the building was removed, excavation is now an implementable alternative. Excavation of the low permeability fill along with the contaminated groundwater would likely reduce contaminant concentrations below target risk-based MCSs. Excavation can be completed using either a long-armed excavator or closely-spaced, large diameter, soil-auger borings.

Summary of Building 51L Corrective Measures Implementation Strategy

The remediation objectives for the Building 51L Groundwater Solvent Plume and source area are to: 1) ensure that groundwater COCs at detectable concentrations do not migrate to surface water through the storm drain system; 2) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs do not migrate into areas where concentrations are less than MCSs; 3) reduce groundwater COC concentrations below target risk-based MCSs; and 4) reduce soil COC concentrations below target risk-based MCSs.

Lining or rerouting the storm drain line so that it does not traverse the plume area is the recommended alternative to meet remediation objective (1). Groundwater extraction will continue until this is accomplished, or until it can be shown that COC concentrations at the point of compliance (the outfall to the creek) are below detectable levels.

No action is needed to meet objective (2) since migration of the plume has not been occurring.

Given the small size of the impacted area, soil excavation and offsite disposal is the recommended alternative to remove contaminated material in both the saturated and unsaturated zones. This measure will meet both objective (3) and objective (4). After excavation has reduced COC concentrations below risk-based levels in the central plume area it is likely that natural attenuation processes will further reduce COC concentrations in the groundwater.

4.3.3 Building 71 Groundwater Solvent Plume (Building 71B Lobe)

The Building 71 Groundwater Solvent Plume extends southwestward from Building 71 and 71B in the Bevalac Area of Berkeley Lab (**Figure 4.3.2-1**). The plume consists of two distinct lobes that have different sources, based on contaminant chemistry, plume geometry, and hydraulic gradient information. The Building 71B and Building 71 lobes extend southwestward from Building 71B and Building 71, respectively, and lobes commingle just north of Building 46A (**Figure 4.3.3-1**). The Building 71 lobe is not discussed further in this document, since VOC concentrations have been decreasing and were below MCLs when wells monitoring the plume were last sampled in July 2003.

The Bevalac Area is described in Section 4.3.1. The Building 71 complex housed the former Super Heavy Ion Linear Accelerator (Super HILAC) and associated support facilities. The Super HILAC is no longer in operation. Building 71B houses a machine shop.

The principal Building 71B lobe constituents are halogenated VOCs that were used as cleaning solvents, including TCE, PCE, and associated degradation products (e.g., cis-1,2-DCE, and vinyl chloride). Based on the results of soil and groundwater sampling, solvent spills that occurred at the location of Building 71B appear to be the primary source for the soil and groundwater contamination.

Two pilot tests and an ICM were conducted to evaluate potential corrective measures alternatives for the Building 71B lobe. The pilot tests consisted of in situ chemical oxidation (ISCO) and enhanced bioremediation using HRC. Reports describing the methodology and results of the pilot tests are included in **Appendix B**. The ICM consisted of excavation of contaminated source area soil from beneath and south of Building 71B.

4.3.3.1 Current Conditions

Geology and Hydrogeology

Bedrock in the Building 71B lobe area is composed of fractured silty sandstone and sandy siltstone of the Orinda Formation. Prior to building construction, the main branch of North Fork Strawberry Creek flowed southwestward from the east end of Building 71 beneath

the west end of Building 71B towards Building 51. During development, a 48-inch concrete pipe was placed in the bottom of the creek to convey surface water, and the channel was filled with artificial fill consisting of clay, gravelly clay, and silty sand. The Building 71B lobe is oriented approximately along the former creek alignment. The surface topography near Buildings 71 and 71B now slopes steeply to the south and southwest toward the Bevatron complex (Building 51).

Groundwater is present in both the Orinda Formation and the surficial fill units, with the depth to groundwater ranging from approximately 10 to 40 feet bgs. Water level fluctuations of more than 10 feet are observed between winter and summer in well MW71B-99-3R in the Building 71B lobe source area.

Based on results of slug tests conducted in monitoring wells, the Orinda Formation has a hydraulic conductivity ranging from approximately 10^{-7} to 10^{-9} meters per second. Based on data from elsewhere at Berkeley Lab, hydraulic conductivities in the artificial fill are expected to be higher (10^{-6} to 10^{-8} meters per second). As shown on **Figure 4.3.3-1**, groundwater monitoring well MW71B-99-3R in the source area can produce more than 200 gpd, whereas groundwater monitoring well MW71B-98-13 in the core area cannot.

The water level elevation contour map for the Bevalac Area is shown on **Figure 4.3.1-3**, and indicates that groundwater flow in the Building 71/71B area is southwestward toward Building 51 (**Figure 4.3.1-3**). The map contours that the horizontal component of the hydraulic gradient (dh/dl) is approximately 0.2 and 0.3 near Building 71B. Assuming a hydraulic conductivity (K) of 1×10^{-7} meters per second for the artificial fill, a gradient of 0.3, and an effective porosity (n_e) of approximately 0.25, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity (v_x) would be 4 meters per year (13 feet per year). For flow in the underlying Orinda Formation bedrock, groundwater velocities would be expected to be approximately an order of magnitude lower.

Groundwater Contamination

The Building 71B lobe contains halogenated non-aromatic VOCs, most of which have been detected at concentrations above MCLs. Chemicals that were detected at concentrations above

MCLs in FY03 are listed in **Table 4.3.3-1**, where the maximum detected concentrations are compared to the target risk-based MCSs. This table includes groundwater samples collected in 2004 from temporary groundwater sampling points installed for the chemical oxidation pilot test. PCE has been detected in the groundwater at concentrations exceeding the target risk-based MCS.

Table 4.3.3-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 71B Lobe of the Building 71 Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 ^(a) (µg/L)	Regulatory-Based Groundwater MCS (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
TCE	277	5	1,594
PCE	5,620	5	343
cis-1,2-DCE	324	6	98,405
vinyl chloride	5.2	0.5	12

^(a) Table also includes groundwater samples collected in 2004 from temporary groundwater sampling points installed for the chemical oxidation pilot test at building 71B.

Note: boldface concentration indicates that the maximum detected concentration of the COC exceeds the target risk-based groundwater MCS.

Groundwater COC Trends

Concentration trends for total halogenated non-aromatic VOCs in the Building 71B lobe are shown on **Figures 4.3.3-2a and 4.3.3-2b**. A long-term decline in groundwater concentrations has been observed from approximately 1992 to the present in wells MW90-3, MW90-4 and MW90-5, monitoring the downgradient portion of the lobe; and the downgradient boundary of the lobe has apparently retreated over the same period. Concentrations of COCs in wells monitoring the upgradient part of the lobe have remained relatively stable over 6 years of monitoring, except for recent changes in the source area that are the result of pilot test operations. Seasonal oscillations in COC concentrations in source area well MW71B-99-3R correlate with oscillations in the water table elevation. These corresponding variations indicate dissolution and leaching of soil contaminants during the rainy season, either when the water table rises into contaminated soils, or from flushing of contaminated soil by surface water infiltration. Leaking storm drain lines in the source area were repaired during the soil excavation ICM to prevent them from being an uncontrolled source of soil flushing.

All of the plume constituents comprise chemicals that represent primary or intermediate compounds in the primary PCE degradation pathway. The relative proportions of plume constituents differ substantially with distance downgradient from the source area. Well MW71B-99-3R, which is located close to the source area, contains more than 90% PCE (**Figure 4.3.3-3**). Well MW71B-98-13, located about 50 feet crossgradient from the source area, and well MW90-3, located approximately 180 feet downgradient, contain approximately 30 to 40% PCE, with the remainder consisting of PCE-degradation products (**Figure 4.3.3-4** and **Figure 4.3.3-5**). The changes in the proportions of plume constituents away from the source area indicate that degradation has occurred during plume migration. The proportions of constituents, however, are similar in both MW71B-98-13 and MW90-3, indicating that degradation may be significant process only close to the source zone, and may not be occurring at a significant rate further downgradient. Excluding the effects of recent pilot tests, the relative proportions of lobe constituents have not changed significantly over time in these wells. This indicates that the rate of degradation does not greatly exceed the rate of COC migration from the upgradient source area.

A chemical oxidation pilot test was conducted in 2003 in the source area. A report describing the test methodology and results is included in **Appendix B**. Reagents (hydrogen peroxide and citric acid) were injected beneath and south of Building 71B, immediately adjacent to MW71B-99-3R. Results of post-pilot test groundwater sampling indicated that although total VOC concentrations decreased during the test, they rebounded to pre-pilot test levels within two months. However, the proportion of PCE dropped substantially relative to the proportion of degradation products (i.e., TCE, cis-1,2-DCE and vinyl chloride) as shown on **Figure 4.3.3-3**. The results suggested that that a reaction (possibly due to bacterial growth stimulated by the presence of carbon in citric acid, a test reagent,) favoring dechlorination was produced by the test. The results of the pilot test indicated that reagents could be delivered with some success to the pore space of the targeted soil volume, and that PCE concentrations could be reduced. However, the method has not been effective in reducing total VOC concentrations in groundwater, either because reagents were not delivered to a sufficient volume of COCs to affect groundwater concentrations, or because advection of COCs into the area occurred after completion of the test.

An enhanced bioremediation pilot test was conducted upgradient from well MW71B-98-13. A pumping test was conducted prior to implementation of the pilot test to assess the feasibility of reagent

injection. The pumping test had the unexpected result of both substantially decreasing PCE concentrations in the pilot test area, and altering the relative proportions of constituents (**Figure 4.3.3-4**). After initiation of the pilot test, PCE and total VOC concentrations continued to decline, and the proportions of degradation products increased. In addition, important indicator parameters such as methane, volatile fatty acid and dissolved hydrogen concentrations also increased. These observations suggest that respiration of microbes associated with reductive dechlorination of COCs had occurred, and that the test was effective in the degradation of COCs. A caveat to this finding is that odor and taste impacts from the use of this technology are significant, and have degraded water quality. In addition, the concentrations of dissolved metals increased substantially in the groundwater.

Soil Contamination

The maximum VOC concentrations detected at the unit were 110 mg/kg PCE, 1.4 mg/kg TCE, and 0.8 mg/kg cis-1,2-DCE. The maximum total VOC concentration detected was in a sample collected at 3.5 feet bgs immediately adjacent to Building 71B (**Figure 4.3.3-6**). To address this contamination, two ICMs were conducted, consisting of excavation of contaminated soil in the areas shown on **Figure 4.3.3-6**.

Concentrations of COCs in residual (post ICM) soil samples are listed in **Table 4.3.3-2**. Also listed in the table are the corresponding target risk-based and regulatory-based soil MCSs. PCE is the only COC detected at a concentration that exceeds target risk-based MCSs for soil. The regulatory-based MCSs would apply to the soil COCs since the well yield is greater than 200 gpd in the source area, where the soil COCs have been detected.

Table 4.3.3-2. Maximum Concentrations of COCs Detected in Soil in the Building 71B Lobe of the Building 71 Solvent Plume Source Area

COC	Maximum Concentration Detected (mg/kg)	Target Risk-Based Soil MCS (mg/kg)	Regulatory-Based Soil MCS (mg/kg)
PCE	47	0.45	0.45
TCE	0.46	2.3	0.46
cis-1,2-DCE	0.45	38	0.19
trans-1,2-DCE	0.039	50	0.67
methylene chloride	0.24	1.8	0.077

Note: boldface concentration indicates that the concentration exceeds the target risk-based soil MCS.

Residual contamination exceeding the MCSs lies along the east side of the excavation and in localized areas where soil could not be safely removed due to building stability concerns. The residual soil contamination constitutes a continuing source of VOCs that dissolve into groundwater.

Surface Water

The hillside beneath Building 71B is drained by several hydraugers (subhorizontal drains) which intercept the Building 71B lobe in the subsurface. Concentrations of COCs in monthly samples of hydrauger effluent have been below or at MCLs, with the exception of hydrauger 51-01-3 and 51-01-3A, which contained cis-1,2-DCE at a maximum concentration of approximately three times the MCL of 6 ug/L. These hydraugers have had a long-term decreasing trend in concentrations. The hydrauger effluent is currently intercepted and piped to a treatment system and discharged to the sanitary sewer. However, if interception of the effluent were discontinued, the groundwater from the hydraugers would be conveyed to the storm drain system and then to surface water in Blackberry Creek. As a result of dilution and volatilization of COCs; and given the relatively low concentrations in the effluent, untreated water conveyed by the storm drain should be below compliance levels (i.e., detectable levels) once it reaches the creek.

Evidence of DNAPL and Residual Soil Contamination

The relatively low concentrations of COCs observed in post-ICM soil samples indicate that free DNAPLs are probably not present at the unit. PCE concentrations detected prior to the ICMs were only slightly below the PCE soil saturation concentration, indicating that DNAPL may have previously been present at the unit. Similarly, PCE concentrations located at the source zone are greater than 1% of solubility, suggesting the presence of DNAPL, although these concentrations may reflect DNAPLs that were removed as a result of the ICMs.

The lack of declining concentration trends or changes in relative proportions of COCs in groundwater (prior to startup of the pilot tests) indicates that residual soil contamination and DNAPL has probably been present within or adjacent to the saturated zone in the vicinity of the source area. During the soil excavation ICMs, soil contaminated with VOCs at concentrations exceeding target risk-based MCSs was found beneath and adjacent to Building 71B, and residual concentrations

exceeding these levels remain in place along the margin of the ICM excavation. However, the mass of contaminants has been significantly reduced by the two ICMs.

4.3.3.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 71B lobe Of the Building 71 Groundwater Solvent Plume:

- Residual soil contamination that exceeds target risk-based MCSs is present beneath Building 71B in the source area of the Building 71B lobe. DNAPLs were likely present in this area in the past, but may have been removed as a result of ICMs. Past rapid increases in groundwater COC concentrations coincident with increased rainfall and groundwater elevation rises suggest that this residual soil contamination resulted in direct impacts to groundwater. The potential for leaching and dissolution of COCs from soil has been substantially reduced as a result of excavation of a significant mass of contaminated soil and diversion of leaking storm drains, although the long-term impact of these actions has not yet been established. Corrective measures at the unit should therefore be based on the remediation of vadose zone soil contamination, and low-level saturated zone residual soil contamination.
- Groundwater flows primarily through relatively low permeability rocks of the Orinda Formation and through surficial units along the former course of Blackberry Creek. The estimated groundwater velocity is roughly 13 feet per year or less.
- Groundwater well yield in the source area is greater than 200 gpd so that regulatory-MCSs are applicable, whereas target risk-based MCSs are applicable to the remaining area of the lobe since well yields are less than 200 gpd.
- Spatial variations in plume chemistry suggest that degradation of COCs in the groundwater has been occurring in near Building 71B during migration, although evidence for degradation in the downgradient portion of the plume is less certain. The lack of a temporal change in the relative proportions of COCs throughout most of the area of the lobe indicates that a state of equilibrium has been reached where degradation rates are similar to rates of desorption and dissolution of soil contaminants and downgradient migration of dissolved COCs. However, concentrations trends indicate that degradation rates may slightly exceed migration rates in the downgradient portion of the lobe.
- Initial results of the ISCO pilot test in the source area indicate that this method was partially effective at delivering reagents in the subsurface, but results were ambiguous in regard to impacts on groundwater COC concentrations.
- Initial results of the enhanced bioremediation HRC pilot test indicate that this method was effective at both delivering reagents in the subsurface, and promoting degradation of COCs in groundwater.

- Migration of COCs beyond the downgradient boundary of the plume does not appear to be occurring, and the decreasing concentration trends observed in wells monitoring this area suggest that the lobe has been retreating.
- Concentrations of COCs are above target risk-based MCSs and regulatory MCSs in both soil and groundwater. The potential human receptor and risk-based exposure pathway of potential concern is exposure to COCs by a hypothetical future indoor worker breathing vapor migrating from the groundwater or soil to indoor air (Berkeley Lab, 2003a).
- Hydrauger effluent derived from the Building 71B lobe contains COCs at concentrations greater than compliance levels. The effluent is currently diverted from storm water discharge and treated at a groundwater treatment system.

4.3.3.3 *Evaluation of Retained Corrective Measures Alternatives*

Concentrations of soil and groundwater COCs in the Building 71B lobe exceed regulatory-based MCSs for a number of COCs, and exceed target risk-based MCSs for PCE. Since well yield in the source area is greater than 200 gpd, regulatory-based MCSs are applicable in this area. No migration of COCs beyond the lobe margins is occurring, so migration control is not a concern. Transfer of COCs to surface water could potentially occur via hydraugers that drain the area, so corrective measures for groundwater should consider this potential impact.

The corrective measures alternatives that are evaluated for the Building 71B lobe and source area are those that were retained in **Table 4.2.3-1** and **Table 4.2.3-2** (for soil and groundwater, respectively). The results of the evaluation are provided in **Table 4.3.3-3** and discussed below.

No Action

No action for the Building 71B lobe would consist of terminating all groundwater monitoring activities and stopping the collection and treatment of hydrauger effluent. Groundwater concentrations of several COCs would likely result in continued impacts to hydrauger discharges above detectable levels for the foreseeable future. As described above; however, concentrations of COCs in hydrauger effluent have been declining and the COC concentrations should be below levels of concern at the creek. Since COC concentrations in groundwater monitoring wells do not show declining trends, the concentration of PCE would likely remain above target risk-based MCSs for the foreseeable future. These conditions would

Table 4.3.3-3. Evaluation of Corrective Measures Alternatives, Building 71B Lobe of the Building 71 Solvent Plume and Source Area

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (c)	Regulatory Agency Acceptance	Community Concerns
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	yes/no	yes	no	yes	2	2	2	4	1	1
Institutional Controls	yes/no	no	no	yes	3	1	3	4	4	2
Groundwater Containment/Capture	no/no	no	no	yes	3	2	3	3	4	4
Surface Water Capture	no/yes	no	yes	yes	4	1	5	4	3	4
Permeable Reactive Barrier	no/no	no	no	yes	3	2	3	3	4	3
Chemical Oxidation	yes/yes	unknown	yes	yes	2	2	2	2	5	5
Soil Vapor Extraction	no/no	no	yes	yes	2	2	2	3	4	4
Thermally Enhanced SVE/DPE	no/no	no	no	yes	3	3	3	4	4	4
Soil Mixing	yes/yes	Yes	Yes	Yes	3	3	3	4	4	4
Enhanced bioremediation	yes/yes	yes	no	yes	4	4	4	4	4	4
Soil Flushing and Groundwater Extraction	yes/no	yes	yes	yes	3	3	4	3	4	4
Excavation with Offsite Disposal	yes/yes	yes	yes	yes	5	5	5	2	5	4

(a) Level of Compliance Ranking

1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance

1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

require establishment of Institutional Controls to protect future indoor workers. In addition, this alternative would likely be unacceptable to the regulator agencies and the community. The No Action alternative is not protective of human health and the environment and is therefore eliminated from further consideration.

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997. As part of this study, geochemical parameters were measured in well MW90-3, located in the downgradient portion of the Building 71B lobe. Concentrations of geochemical indicator parameters, particularly the relatively high dissolved oxygen concentration, measured in this area were not favorable for natural degradation processes. However, observed ratios of parent-daughter compounds within the plume strongly suggest that degradation occurs in the upgradient portion of the plume during migration, and results of the enhanced biodegradation HRC pilot test indicated that biodegradation can be successfully enhanced in this area. Since a large fraction of the soil COCs in the plume source area have been removed, natural attenuation through biodegradation may be a favorable method for the upgradient portion of the lobe, and the reduction in COC concentrations in the upgradient area would lead to declining concentrations in the downgradient portion of the lobe where conditions suitable for biodegradation do not appear to be present. These observations indicate that MNA could be an effective alternative if the residual soil COCs in the source area that constitute a continuing source of groundwater contamination can be significantly reduced.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The groundwater plume is stable so no containment or capture of the plume boundary is currently required or planned. However, contaminated hydrauger effluent is currently collected and treated to prevent discharge of contaminated water to surface water, so continuing capture and treatment is required as a regulatory compliance measure until discharge to surface water is shown to be below detectable levels.

For the source area soil contamination, containment through capping would reduce the risk to human health; however, it is not recommended since it would likely be unacceptable to the community and its long-term effectiveness would be uncertain without continued maintenance.

Permeable Reactive Barrier/Funnel and Gate

A permeable reactive barrier or funnel and gate system would serve a similar function to a groundwater capture system. Therefore, as noted above, no capture of the plume boundary is currently required or planned. This alternative is therefore not recommended.

Chemical Oxidation

The pilot test indicated that chemical oxidants could be delivered to subsurface soils at the unit, but that the effectiveness of the method for remediating groundwater is questionable as indicated by the short-lived nature of the observed concentration changes. However, the method may be effective at treating localized areas of soil contamination that are inaccessible to other technologies, such as the small zones of contaminated soil that remain adjacent to foundation members beneath Building 71B, although this application of the method was not pilot-tested, so its effectiveness is unknown. Since few other technologies could be implemented in these small zones of soil contamination, and the scale of a pilot test would be similar to full-scale application, it is recommended that this technology be implemented for “hot spot” cleanup of residual soil COCs at the unit.

Soil Vapor Extraction (SVE) and Thermally Enhanced Dual Phase Extraction (DPE)

The effectiveness of SVE systems is controlled by both contaminant volatility and subsurface vapor flow. The solvents detected at the Building 71B lobe source area are highly volatile and can be

easily removed from soil and groundwater if sufficient vapor flow through the soil can be established. Thermal heating, in combination with dewatering, dries the soil thereby increasing the effectiveness of an SVE system. However, the method is not effective in low permeability materials (such as the silt and clay material comprising the artificial fill at Building 71B), which still retain excess moisture even with soil drying. In addition, due to the high capital and operating cost of treating a small area such as the Building 71B lobe source area, this alternative is not recommended.

Soil Mixing

Since the remaining soil COCs at the Building 71B lobe source area lie beneath Building 71B, it is not feasible to implement soil mixing at this unit.

Enhanced Bioremediation

Pilot-test data indicate that enhanced bioremediation is an implementable and potentially effective technology in the upgradient portion of the Building 71B lobe. Resultant reductions in groundwater COC concentrations would contribute to attenuation of COC concentrations in downgradient areas. A possible negative effect of HRC is that HRC reagents cause declines in groundwater taste and odor quality and increases in dissolved metals concentrations in the groundwater. However, these declines in groundwater quality should be fairly localized and short term. Enhanced bioremediation is therefore recommended.

Soil Flushing and Groundwater Extraction

During implementation of the ICMs, leaking storm drains that probably contributed to leaching of COCs from the soil to groundwater were found to be located within the Building 71B lobe source area. Since a significant quantity of COCs is still sorbed to the soil matrix in this area, soil flushing could possibly result in increased mobilization of contaminants into the dissolved phase in that area. Clean water from the storm drain effluent could be injected into the gravel-backfilled ICM excavation located at the upgradient edge of the source area soil contamination, and captured by downgradient extraction well(s) or an extraction trench. Application of this technology has been effective in reducing COC concentration levels at the Former Building 7 sump, the source of the Building 7 lobe of the Old Town Groundwater Plume.

Prior to implementing this alternative, however, testing should be completed to assure that the injected water would be captured. This technology is recommended for the Building 71B lobe.

Excavation with Offsite Disposal

Excavation has been effective in removing the contaminated source area soil that is accessible. However, the degree of source removal has been limited due to engineering concerns regarding the stability of the foundation of Building 71B. Most of the contaminated soil that remains is adjacent to foundation members beneath the building, and is not accessible for excavation. Additional excavation is therefore not recommended as a final corrective measure, except for limited areas that are accessible.

Summary of Building 71 Lobe Corrective Measures Implementation Strategy

The remediation objectives for the Building 71B lobe are to: 1) ensure that groundwater COCs above compliance levels (i.e., detectable concentrations) do not migrate to surface water; 2) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs (MCLs) do not migrate into areas where concentrations are less than MCLs; 3) reduce groundwater COC concentrations in the source area where well yield is greater than 200 gpd to below regulatory-based MCSs and target risk-based MCSs; and, 4) reduce soil COC concentrations below target risk-based MCSs. Continuation of surface water capture of hydrauger effluent is required to address objective (1) above, until it can be shown that COC concentrations at the point of compliance (the outfall to the creek) are below levels of detection.

Alternatives recommended to meet objectives (3) and (4) will also help meet objective (2). In addition, after the source area has been remediated and or migration from the source area has been controlled, enhanced bioremediation using HRC can be used to further reduce COC concentrations in the area downgradient from the source.

Soil flushing, chemical oxidation (for unsaturated zone soils only) and excavation with offsite disposal have been identified as potentially effective corrective measures alternatives to meet remediation objectives (3) and (4). A combination of these technologies is recommended for the source zone of the Building 71B lobe. Additional excavation beyond the existing ICM excavations should be conducted to remove soils that are accessible. Despite somewhat

ambiguous results pertaining to groundwater COCs, chemical oxidation may potentially be effective in targeting soil in areas not accessible to excavation, and is the only screened technology that could potentially be applied to areas of contamination surrounding foundation members in the source area. Therefore, this technology is proposed for targeting areas not accessible to excavation.

4.3.4 Building 7 Lobe of the Building 7 Groundwater Solvent Plume (AOC 2-4) and the Former Building 7 Sump (AOC 2-5)

Berkeley Lab (at that time known as the Radiation Lab) moved from the UC Berkeley campus to its present location in 1940 in order to construct the 184-Inch Cyclotron, a historic facility used to accelerate atomic particles for use in nuclear physics experiments. The area of the cyclotron building (the original Building 6) and adjacent support shops and laboratories to the north and east of Building 6 formed the core of Berkeley Lab operations throughout the 1940s, and therefore is commonly referred to as "Old Town". Redevelopment of the Old Town Area in the late 1980's resulted in replacement of the 184-Inch Cyclotron building (the original Building 6) with the Advanced Light Source building (the present Building 6) and construction of Building 2, which houses the Advanced Materials Laboratory.

The Old Town Groundwater Solvent Plume is a broad, multi-lobed groundwater plume, composed primarily of halogenated non-aromatic VOCs, which underlies much of the Old Town area. The geometry and distribution of chemicals in the plume indicate that it consists of three coalescing lobes that were originally discrete plumes derived from distinct sources (**Figure 4.3.4-1**). The Building 7 lobe (AOC 2-4) contains significantly higher VOC concentrations than the other two plume lobes, and extends northwestward from the northwest corner of Building 7 to the parking area downslope from Building 58.

Leaks and/or overflows of halogenated non-aromatic hydrocarbons (primarily PCE) from an abandoned sump (the Former Building 7 Sump ([AOC 2-5]) that was located north of Building 7 were the source of the contamination. The COCs were initially released as free product to the soil around the sump and then migrated as DNAPLs into the saturated zone. A sufficient mass of either residual or free-phase DNAPLs remains in the source area to constitute a continuing source of groundwater contamination.

Continuing dissolution of COCs from the soil and westward to northwestward flow of the groundwater from the sump area has resulted in the development of the Building 7 lobe. Originally, the Building 7 lobe was most likely a distinct groundwater plume, but it has coalesced with other plumes (the current Building 52 lobe and Building 25A lobe) associated

with other discrete sources in the Old Town Area. The coalesced plumes now constitute the three main lobes of the Old Town Groundwater Solvent Plume.

Extensive sampling of the soil and groundwater was conducted between approximately 1992 and 2003 to characterize the magnitude and extent of COCs in both the area of the former Building 7 Sump, the source area, and in the core areas of the Building 7 lobe. During this period, ICMs were implemented where they were determined to be necessary to protect human health and the environment. In addition, pilot testing was conducted to evaluate the effectiveness and implementability of potential remedial technologies. The ICMs and pilot tests are listed in **Table 4.3.4-1**. The locations of these ICMs and pilot tests are shown on **Figure 4.3.4-2**.

4.3.4.1 *Current Conditions*

Physiography and Surface Water Hydrology

Most of the developed portion of the Old Town Area lies atop a roughly triangular topographic bench bounded on the west by the Building 6 complex and the west-facing Building 53/58 slope, on the south by the south-facing slope above Strawberry Creek, and on the east by Building 26 and a southeast-facing slope (**Figure 4.3.4-3**). Prior to development, a drainage course flowed from the Building 6 area through the current location of Building 58, continuing northwestward to a confluence with North Fork Strawberry Creek in Blackberry Canyon. This drainage was filled during site development. Downgradient (west) of Building 58, the Building 7 lobe is approximately coincident with the former drainage course.

Surface runoff consists of overland flow off paved and unpaved areas, which is directed to storm drains (**Figure 4.3.4-4**) which discharge into North Fork Strawberry Creek. Storm drain inspections have shown breaks in some of the lines, indicating that water may leak both out of and into the storm drain system at some locations. Known breaks were identified just west of the former Building 7 sump, and were repaired in 2003. Prior to repair, these breaks probably constituted sources of artificial groundwater recharge during the rainy season.

Table 4.3.4-1. Summary of ICMs and Pilot Tests Conducted for the Former Building 7 Sump and the Building 7 Lobe

Date	Location	Comments
Excavation and Removals		
1992	Source location	Removal of the contents (free product) in the Building 7 Sump, the source of the Building 7 lobe.
1995	Source location	Removal of the Building 7 Sump and excavation of source area soil to a depth of 17 feet to remove highly contaminated soil and free product.
In-Situ Soil and/or Saturated Zone Flushing		
1996 ongoing	Source zone immediately downgradient from the Former Building 7 Sump location	<p>Groundwater extraction from the Building 7 Groundwater Collection Trench. Treatment of extracted groundwater with a Granular Activated Carbon (GAC) treatment system, and recirculation of the treated water into the 17-foot deep (approximate top of saturated zone) gravel-filled sump excavation.</p> <p>Method has been effective in reducing concentrations of COCs in the groundwater and soil in the source zone and controlling downgradient migration of groundwater COCs.</p>
1998 ongoing	Leading edge	<p>Extraction of groundwater from the Building 58 West Groundwater Collection Trench at the downgradient edge of Building 7 lobe. Installed to control migration of the downgradient edge of the Building 7 lobe.</p> <p>Method has been effective in controlling migration of the leading edge of the Building 7 lobe.</p>
1999 ongoing	Core zone	<p>Extraction of groundwater and soil gas from the Building 58/58 Slope Groundwater Collection Trench. Starting in October 2003, treated groundwater was discharged on the slope above the collection trench to flush the downslope core zone.</p> <p>Method has been effective in controlling downgradient migration of the core zone. Effectiveness in reducing contaminant mass has not been determined.</p>
2002 ongoing	Downgradient edge of the core zone	<p>Extraction of groundwater from Building 58 East Groundwater Collection Trench. Starting in October 2003, treated groundwater was discharged on the slope above the collection trench to flush the downslope core zone.</p> <p>Method has been effective in controlling downgradient migration of the core zone. Effectiveness in reducing contaminant mass has not been determined.</p>
2002-ongoing	Core zone downgradient from the Building 7 Groundwater Collection Trench.	<p>Injection of treated groundwater into six injection wells. Capture of the injected water at three downgradient extraction wells and from the upgradient collection trench.</p> <p>Effectiveness in reducing COC concentrations in groundwater in core zone has not been determined.</p>

Thermally Enhanced Soil Vapor Extraction Pilot Test		
2001 ongoing	Source zone immediately downgradient from the Former Building 7 Sump	Conductive electrical heating of soil in three boreholes combined with extraction of both soil vapor and groundwater from one central and three peripheral extraction wells. Method has been effective in removing contaminant mass from the source zone
In Situ Methanotrophic Treatment Technology (MTT) Pilot Test		
2000	Building 7 lobe core zone downgradient from the Building 7 Groundwater Collection Trench	A mixture of air, methane, nitrous oxide, and triethylphosphate was injected into the subsurface to stimulate the growth of microorganisms. Method was not effective in reducing contaminant mass in the groundwater in the core zone
Migration Control Compliance Measure		
1998	Building 7 lobe periphery zone	A drain line was plugged and a sump was installed to capture contaminated effluent to prevent migration of contaminated water through the drain system to surface water. Method has been effective in controlling migration of contaminated water to surface water.

Geology

The Building 7 lobe area is underlain at relatively shallow depth by three main bedrock units (**Figure 4.3.4-5**). The Orinda Formation is the deepest-encountered rock unit, and extends to a depth greater than 190 feet near Building 53. The Orinda Formation is overlain by volcanic and volcanoclastic rocks of the Moraga Formation over much of the northwestern part of the Old Town Area. Although some outcrops of Moraga Formation appear to be relatively undisturbed, most outcrops consist of loosely consolidated, poorly sorted, angular blocks composed of Moraga Formation rock types (andesitic volcanic breccia, andesite, thin sandy siltstone layers, volcanoclastic gravelly sandstone, and minor basalt).

In many places, rocks found along the contact between the Moraga and Orinda Formations comprise a mixture of rock types common to both formations, and are mapped as the “Mixed Unit”. The Mixed Unit appears to represent structurally interleaved portions of the Moraga and Orinda Formations. Rocks of both the Moraga Formation and Mixed Unit in the Building 7 Area are interpreted to represent ancient landslide deposits emplaced before development of the current topography.

Overlying the bedrock, a thick section of colluvium is present in the lower part of the former drainage course immediately beneath and west of Building 58. The colluvium is overlain by up to 40 feet of artificial fill that was placed in the drainage course that flowed from the vicinity of Building 6 through the current location of Building 58. Alluvium and colluvium are relatively thin in other parts of the Building 7 Area.

As shown on **Figures 4.3.4-6 and 4.3.4-7**, the contacts between these units dip northward to northwestward in the Building 7 lobe area. In general, the upper contact of the Orinda Formation has high relief, forming bowl-shaped depressions that are occupied by the Mixed Unit, Moraga Formation, colluvium, and artificial fill (**Figure 4.3.4-8**).

Hydrogeology

The surficial units (i.e., alluvium, colluvium and artificial fill) are generally above the water table, except for colluvium within the former drainage course that trends northwestward beneath Building 58 (**Figures 4.3.4-8**). Slug tests and pumping tests of wells have shown that both the Orinda Formation and the Mixed Unit have relatively low hydraulic conductivities, typically on the order of 10^{-8} to 10^{-9} meters per second. Deep horizons of the Orinda Formation (>130 feet bgs) intercepted by a four-level well cluster (MW53-92-21) immediately north of the Building 7 lobe have even lower hydraulic conductivities, on the order of 10^{-12} to 10^{-13} meters per second. These data indicate that groundwater flow in the Orinda Formation in this area is insignificant, which is verified by the negligible to nondetectable levels of contamination observed in wells screened within the Orinda Formation.

The Moraga Formation volcanic rocks that occupy depressions in the undulatory upper contact of the Orinda Formation have relatively high hydraulic conductivities (typically on the order of 10^{-4} to 10^{-6} meters per second) in comparison to the underlying units, and therefore constitute preferential flow pathways. For this reason, the structure of this undulatory contact between the Orinda Formation and the overlying units has a strong influence on groundwater flow. The contact is illustrated on cross-section A-A' (**Figure 4.3.4-8**). The hydraulic conductivity of colluvium below Building 58 along the downgradient portion of the Building 7 lobe is unknown, but is expected to be intermediate between those measured for the Moraga and Orinda Formations.

Water level elevation contours (**Figure 4.3.4-9**) show that groundwater generally flows northwestwards in the Building 7 Area, although, flow is locally deflected to the north in the vicinity of Building 53, to the north of Building 7. This local northward-directed flow is due to the geometry of contacts between relatively low hydraulic conductivity Orinda Formation rocks and higher hydraulic conductivity Moraga Formation and Mixed Unit rocks. **Figure 4.3.4-10** shows the distribution of geologic units at the water table in the Old Town Area, which affect the groundwater flow pathways. Groundwater flow directions are also locally influenced by groundwater extraction and reinjection associated with ongoing pilot tests and ICMs located primarily west and northwest of Building 7.

Groundwater flow modeling has been conducted for the Old Town Plume, including the Building 7 lobe, using the ITOUGH2 code (Zhou and others, 2004; Preuss and others, 1999). The modeling, along with slug test data, was used to estimate rock physical characteristics (i.e., hydraulic conductivity and effective porosity) based on matching of seasonal variations in groundwater elevations. Modeled flow velocities are typically between 0.1 and 1 feet per day (37 to 365 feet per year) within the core of the Building 7 lobe, although velocities in the downgradient periphery are somewhat greater (**Appendix D**), indicating that groundwater at the head of the Building 7 lobe would take several years to reach the toe of the lobe.

Groundwater wells in the Building 7 lobe central core zone generally yield less than 200 gpd, whereas wells in the area immediately surrounding the central core zone have short-term yields greater than 200 gpd (**Figure 4.3.4-11a**).

Groundwater Contamination

The principal Building 7 lobe constituents are halogenated non-aromatic VOCs that were used as cleaning solvents, including PCE and carbon tetrachloride, and their associated degradation products (e.g., TCE 1,1-DCE, cis-1,2-DCE, and vinyl chloride), most of which have been detected at concentrations above MCLs. In addition, benzene, an aromatic VOC, has been detected in one deep well in the vicinity of the lobe, but does not appear to be associated with the Building 7 lobe and may be naturally occurring. Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.4-2**, where the maximum detected concentrations are compared to the target risk-based MCSs.

Table 4.3.4-2. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 7 Lobe of the Old Town Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Regulatory-Based Groundwater MCS (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
TCE	79,300	5	1,594
PCE	76,035	5	343
carbon tetrachloride	4,600	0.5	27
cis-1,2-DCE	1,240	6	98,405
trans-1,2-DCE	13	10	94,405
1,1-DCE	550	6	28,873
chloroform	150	100	1,206
methylene chloride	1,600	5	10,381
1,1-DCA	44.6	5	3,663
1,2-DCA	6.6	0.5	1,030
1,2-dichloropropane	7.2	5	1,071
vinyl chloride	75	0.5	12
1,1,2-TCA	8.1	5	1,905
Benzene	8.9	1	175

Note: boldface concentration indicates that the maximum detected concentration of the COC exceeds the target risk-based groundwater MCS.

Distribution of COCs

The highest contaminant concentrations are found in wells along the elongate core of the Building 7 lobe northwest (downgradient) of the former Building 7 sump (**Figure 4.3.4-11a and Figure 4.3.4-11b**). The vertical distribution of total halogenated non-aromatic VOCs in the Building 7 lobe is depicted on cross section A-A' (**Figure 4.3.4-12**). Isoconcentration contours on the cross section depict a steep concentration gradient across the contact between the Moraga Formation and the underlying Orinda Formation below the core of the Building 7 lobe. This observation is commonly observed in other areas of the Old Town plume where closely located wells are screened at multiple depth horizons (Berkeley Lab, 2000).

Prior to 1997, the highest concentrations were detected in the source area immediately adjacent to the Former Building 7 Sump in monitoring well MW7B-95-21. Concentrations have declined in that well due to extraction and treatment of groundwater from the Building 7 Groundwater Collection Trench. The highest VOC concentrations are now detected in the core area in wells MP7-99-1B and MW58-00-12, both of which contain approximately 90,000 µg/L of halogenated VOCs, composed primarily of nearly equal concentrations of PCE and TCE.

Groundwater COC Trends

Concentration trends for total halogenated non-aromatic VOCs in the Building 7 lobe are shown on **Figures 4.3.4-13a, 4.3.4-13b, 4.3.4-13c, 4.3.4-13d and 4.3.4-13e**. The concentrations of VOCs detected in most of the wells monitoring the lobe have been relatively stable or have declined. The declining trends, particularly in the source area, are primarily the result of the ICMs and pilot tests that have been implemented. The most marked long-term decline in concentrations has been observed in monitoring well MW7B-95-21, which is located between the Former Building 7 Sump and the Building 7 Groundwater Collection Trench. The concentration of total halogenated VOCs detected in MW7B-95-21 has declined from approximately 300,000 µg/L to 10,000 µg/L or less. This decline is attributed primarily to the effects of soil flushing. Concentrations have remained low since soil flushing was halted at the beginning of 2003.

In situ soil flushing has had mixed results in reducing COC concentrations in the Mixed Unit. The Building 7 soil flushing pilot test consists of injection of treated-groundwater into six injection wells in the lobe core area, with the saturated screen intervals of the wells within the Mixed Unit. The test has resulted in significant declines in COC concentrations in MW7-95-23, which is screened in the Mixed Unit and Orinda Formation (**Figure 4.3.4-13b**). However, flushing has not resulted in observable effects on COC concentrations measured in core area wells screened solely within low permeability rocks of the Mixed Unit (e.g., wells MP7-99-1B and MP7-99-2B). The soil flushing pilot test was expanded in 2003 to include discharge of treated-groundwater to surface soil at the top of the Building 53/58 slope and into well MW53-93-16. As a result of this action, groundwater COC concentrations have declined to approximately

50% of the pre-injection levels in well MW58-00-12. MW58-00-12 is screened in the Mixed Unit and Orinda Formation, indicating that flushing of the Mixed Unit may be effective in some areas.

The proportion of dissolved PCE degradation products (e.g., TCE and cis-1,2-DCE) relative to PCE increases with distance downgradient from the source area, indicating that Building 7 lobe constituents have degraded as they have migrated. This is illustrated by comparing the relative proportions of parent to daughter products in wells MW7-92-19 (source area well), MW58-93-3, and MW58A-94-14 (downgradient well) (**Figure 4.3.4-14a**, **Figure 4.3.4-14b**, and **Figure 4.3.4-14c**).

The general downgradient decrease in the ratio of parent to daughter products indicates that degradation of constituents occurred during initial migration of the plume; however, recent data indicate that for the lobe core area, migration has superseded degradation as the dominant fate process. This is illustrated in well MW58-93-3, located at the downgradient edge of the core where the proportion of PCE has increased relative to its degradation products (**Figure 4.3.4-14b**). However, the available data suggest that natural degradation is the dominant fate process downgradient (west) of Building 58. This is illustrated in well MW58A-94-14, at the leading edge of the lobe, where long-term decreases in both the total concentration of halogenated VOCs and the parent to daughter ratio are observed (**Figure 4.3.4-14c**). These conclusions are supported by the site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs that was conducted in 1997. The data collected were generally not indicative of conditions favorable for natural degradation throughout most of the Building 7 lobe, except for the downgradient area (MW58A-94-14) where a relatively low dissolved oxygen concentration was measured.

Soil Contamination

Pre-Remediation Soil Contamination

In 1992, an abandoned concrete sump was discovered between Buildings 7 and 7B (**Figure 4.3.4-15**). The sediment and liquid within the sump and soil covering the ditch were sampled and removed. PCE (free product) was detected in the sump. Soil investigations conducted between 1992 and 1995 showed that PCE was the primary contaminant, with TCE,

1,1,1-TCA, cis-1,2-DCE, and 1,1-DCE also detected at relatively high concentrations. The maximum PCE concentration in soil (14,000 mg/kg) was detected at a depth of 2.8 feet, within a few feet of the sump. Elevated PCE concentrations (>100 mg/kg) were generally restricted to the upper 20 feet of soil within a few feet south and west of the sump. The PCE concentrations measured in soil below the water table were generally less than 100 mg/kg. A zone of elevated concentrations exceeding 1 mg/kg was detected within the Mixed Unit in an area extending westward from the sump (**Figure 4.3.4-16**).

Post-Remediation Residual Soil Contamination

ICMs and Pilot Tests

In 1992, the concrete slab covering the sump was removed, and the sediment and liquid in the sump, and soil filling the adjacent concrete ditch, were removed and disposed. In 1995, the sump was removed and approximately 70 cubic yards of the surrounding contaminated soil was excavated to a depth of 17 feet from an area approximately 10 feet long by 7 feet wide (**Figure 4.3.4-15**). These ICMs resulted in the removal of a large fraction of the highly contaminated vadose zone soil from the site, although soil remaining at the base of the excavation contained up to 1,000 mg/kg PCE.

Subsequent to the soil-removal ICMs, the contaminant mass immediately downgradient from the former sump location has been reduced by: 1) groundwater injection and soil flushing between the Building 7 sump ICM excavation and the Building 7 Groundwater Collection Trench; and 2) operation of the thermally enhanced DPE pilot test.

Groundwater infiltration into the gravel-filled ICM excavation was initiated in 1997, using treated groundwater extracted from the Building 7 collection trench. The infiltrating groundwater has leached downward to the saturated zone and then flowed northwestwards and been recaptured by the Building 7 Groundwater Collection Trench. This process was been generally continuous from May 1997 through June 2001, at which time infiltration was discontinued to help improve the effectiveness of the thermally enhanced DPE pilot test. Almost two million gallons of treated water was pumped into the remedial excavation and approximately 50 kg of VOCs were removed

from the groundwater during this period, indicating an average removal rate of slightly less than 1 kg/month, which declined asymptotically to very low levels.

Confirmation soil samples collected from the floor of the ICM excavation prior to groundwater infiltration had concentrations between 300 and 1,000 mg/kg total VOCs (**Figure 4.3.4-17**). Soil sampling conducted through the excavation backfill in 2002 (SB7HTC-02-1) and 2003 (SB7-03-2), approximately five years after injection of treated groundwater was initiated, indicated that VOCs in soil beneath the central part of the ICM excavation had been significantly reduced by flushing (0.09 mg/kg total VOCs maximum). However, concentrations of VOCs in soil at the west edge of the excavation were essentially unchanged (720 mg/kg total VOCs maximum), indicating that the effects of flushing were localized.

The thermally enhanced DPE pilot test started operating in July 2001, and has operated primarily during the summer and fall seasons since that time. The system consists of three heater wells, four DPE wells, and two instrument wells (**Figure 4.3.4-17**). Starting in October 2003, the system was enhanced by injection of hot air under pressure. Approximately 700 kg of contaminant mass have been removed from the extracted soil gas during this period, indicating an average removal rate greater than 1 kg/day.

Residual Soil COC Concentrations

Residual contamination primarily consists of PCE, which was present at a maximum concentration of 3,000 mg/kg in heater instrument well HI7-00-1. As shown on **Figure 4.3.4-17** and **Figure 4.3.4-18**, most of the soil near the former Building 7 sump contains relatively low concentrations of VOCs (<1 mg/kg), and soil containing elevated VOC concentrations is confined to relatively thin zones that are generally less than 5 feet thick. Maximum detected concentrations of VOCs in soil remaining after excavation are shown in **Table 4.3.4-3**.

Table 4.3.4-3. Maximum Concentrations of COCs Detected in Soil at the Former Building 7 Sump

COC	Maximum Concentration Detected (mg/kg)	Target Risk-Based Soil MCS (mg/kg)	Regulatory-Based Soil MCS (mg/kg)
PCE	3,000	0.45	0.7
TCE	60	2.3	0.46
cis-1,2-DCE	0.043	38	0.19
1,1,1-TCA	11	690	7.8
1,1-DCA	0.024	1.3	0.2
1,1-DCE	0.16	8	1.0
Benzene	0.0091	0.1	0.044
Carbon tetrachloride	10	0.05	0.11
Chloroform	0.092	0.28	2.9
Vinyl chloride	0.0049	0.0035	0.085

Note: boldface numbers indicate concentrations above target risk-based MCS.

Most of the VOC concentration data depicted on the figures were collected prior to startup of the thermally enhanced SVE pilot test. Removal of VOCs by the pilot test has occurred approximately within the heated zone shown on the figures, and VOC concentrations within the zone have likely decreased significantly below those shown.

Soil samples have been collected from a number of borings located west of the Building 7 collection trench. Halogenated VOC concentrations in these borings are generally orders of magnitude lower than those detected east of the collection trench, with the maximum concentrations (4.1 mg/kg PCE and 2.4 mg/kg TCE) detected in boring SB7B-95-7, located approximately 50 feet west of the collection trench. Both PCE and TCE concentrations in groundwater samples from wells (MP7-99-1B and MP7-99-2B) near this boring are approximately 40,000 µg/L. Assuming a soil porosity of approximately 25%, and a bulk density of approximately 1.6, the mass of TCE or PCE dissolved in groundwater alone would be sufficient to result in soil concentrations of approximately 6 mg/kg. This observation indicates that the soil results west of the Building 7 collection trench are likely indicative of groundwater contamination, rather than residual soil contamination in the soil samples.

Evidence of DNAPL

PCE was detected at concentrations substantially above its estimated Berkeley Lab soil saturation concentration of 178 mg/kg (**Table 4.2.2-1**) in a number of samples collected between the Former Building 7 Sump and the Building 7 Groundwater Collection Trench (**Figure 4.3.4-17 and Figure 4.3.4-18**). These relatively high concentrations indicative of the presence of free-phase DNAPL were present in several relatively thin zones within the Mixed Unit, extending to a maximum depth of approximately 35 feet. Given the large mass of VOCs that has been extracted during operation of the thermally enhanced SVE pilot test, it is likely that the volume of DNAPL has been reduced in the pilot test area; however, some DNAPL probably still remains based on the PCE concentration of 720 mg/kg (above the soil saturation level) detected in a soil sample collected from boring SB7HTC-02-1 in 2002.

In addition to inferences drawn from soil concentration data, groundwater samples collected from MW7B-95-21 located between the Former Building 7 Sump and the groundwater collection trench exceeded 1% of effective pure-phase volatility criteria for PCE and TCE, indicating that free-phase DNAPL was likely present. Although concentrations have declined in MW7B-95-21 to well below the solubility criteria, samples collected from lysimeters at several depth horizons in the heater test instrument wells have groundwater concentrations close to or in excess of 100% of PCE solubility, indicating the presence of DNAPL within the samples.

The presence of DNAPL in the area downgradient from the Building 7 Groundwater Collection Trench, is uncertain. PCE concentrations have been below soil saturation levels in all of the samples collected west of (downgradient) from the Building 7 Groundwater Collection Trench. The soil data, however, cannot rule out the presence of DNAPL since the sampling intervals were primarily 5 feet or greater, generally insufficient to delineate DNAPL-impacted zones, and sampling depths may have been too shallow to detect DNAPL that migrated downdip within the Mixed Unit.

Groundwater COC concentrations exceed 1% of their solubilities in several wells downgradient from the Building 7 Groundwater Collection Trench. The area of the Building 7 lobe where concentrations of PCE exceed 1% of solubility (i.e., approximately 2,000 ug/L) coincides with the Building 7 lobe core area shown on **Figure 4.3.4-19**. However, the area in

which DNAPL might be present would likely to be smaller, since the groundwater concentrations are controlled by the hydraulic and chemical characteristics of the plume (i.e., dispersion, diffusion, retardation, etc), in addition to the rate of dissolution of DNAPL into the groundwater.

The Building 7 Groundwater Collection Trench penetrates into the relatively low permeability Orinda Formation, below the deepest levels where elevated soil VOC concentrations have been detected in soil samples. Therefore, it is assumed that the collection trench intercepts essentially all groundwater contamination and DNAPL migrating from the source area. If this is the case, and if DNAPL is not present downgradient from the collection trench, then groundwater COC concentrations should have declined in the downgradient area as the cut-off portion of the lobe migrated downgradient away from the trench. For wells located approximately 10 feet or more downgradient from the collection trench (e.g., MP7-99-1B, MP7-99-2B, and MW7B-95-24), COC concentrations have remained relatively stable at concentrations greater than 10% of solubility. This suggests either that DNAPL is present west of the collection trench, or that groundwater velocities are so low that the lobe is essentially stagnant in this area.

4.3.4.2 *Conceptual Model*

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 7 lobe of the Old Town Groundwater Solvent Plume and the Former Building 7 Sump source area:

- The only known DNAPL in the Building 7 area lies in thin, generally westward-dipping zones of fractured rock of the Mixed Unit in the area between the Former Building 7 Sump and the Building 7 Groundwater Collection Trench. The DNAPL is present in the saturated zone in thin layers between approximately 20 and 35 feet bgs, and continues to provide a source for dissolution of contaminants into groundwater. Migration of COCs from the source area is prevented by continuing operation of the Building 7 Groundwater Collection Trench.
- No definitive evidence exists for the presence of residual or free-phase DNAPL west of the trench, so contamination consist primarily of dissolved-phase COCs in groundwater equilibrium with sorbed COCs derived from the migration of dissolved contaminants. However, it is possible that some undetected DNAPL may be present in this area. Operation of two additional groundwater collection trenches prevents further migration of the core area.

- Within the core of the Building 7 lobe, relatively permeable rocks of the Moraga Formation are thin or absent at the water table. Groundwater contaminants are primarily present in lower permeability rocks of the Mixed Unit because groundwater flow flushes contaminants from the higher permeability Moraga Formation. The low permeability of the Mixed Unit hinders flushing and results in retention of contaminants.
- The Building 7 lobe is elongated along the direction of groundwater flow, consistent with advection being the predominant contaminant transport mechanism, as would be expected given the relatively steep groundwater gradients and moderate permeabilities of the upper portion of the saturated zone. Estimated groundwater velocities are relatively slow, less than 1 meter per year in the Mixed Unit and Orinda Formation.
- Wells within the core of the Building 7 lobe generally have sustainable yields of less than 200 gpd, so target risk-based MCSs are applicable in this area. However, most wells in the lobe periphery have short-term yields exceeding the 200 gpd criteria, so regulatory-based MCSs (MCLs) are applicable in that area.
- Contaminant concentrations and hydraulic conductivity values decrease with depth, as indicated by analytical data from multi-well clusters and hydraulic test data. Advective transport downward into, and laterally within, the deeper horizons of the Orinda Formation, is insignificant.
- Spatial and temporal concentration trends suggest that degradation of VOCs occurred during initial migration of the Building 7 lobe to its present configuration. However, evidence of continued degradation is lacking except in one well located at the downgradient edge of the lobe.
- Concentrations of COCs exceed target risk-based MCSs in groundwater in the source and core areas, and PCE and TCE exceed target risk-based soil MCSs in the source area. The potential human receptors and risk-based exposure pathways of potential concern are exposure to COCs by hypothetical future indoor workers breathing vapor migrating to indoor air from soil or from groundwater, by landscape maintenance workers breathing vapor migrating to outdoor air from soil, and by intrusive construction workers contacting groundwater (Berkeley Lab, 2003a).

4.3.4.3 Evaluation of Retained Corrective Measures Alternatives

For the purpose of evaluating corrective measures alternatives and recommending the technology to implement, the Building 7 lobe was divided into the following three discrete areas, based on different remediation objectives (**Figure 4.3.4-19**).

- 1) The lobe *source area* contains both soil and groundwater COCs at concentrations exceeding target risk-based MCSs. In addition, DNAPL is known to be present.

- 2) The lobe *core area* comprises an elongate zone of dissolved groundwater COCs at concentrations that exceed target risk-based MCSs. The presence of DNAPL in this area is uncertain; however, given the relatively high concentrations of some COCs in the groundwater, this area may also contain some DNAPL that migrated from the source area prior to construction of the Building 7 Groundwater Collection Trench. It is also likely that COCs are sorbed to the soil in this area as the result of sorption of COCs from the groundwater.
- 3) The lobe *periphery area* surrounds the core area and comprises an extensive zone of dissolved groundwater COCs at concentrations exceeding regulatory-based MCSs (MCLs). Since COC concentrations in the groundwater in the periphery are below target risk-based MCSs, cleanup of this area is considered a lower priority than cleanup of the source and core areas. In addition, remediation of the periphery area would likely not be effective until cleanup of the core is sufficient to prevent the migration of groundwater COCs into the periphery at concentrations above the applicable MCSs.

Alternatives Applicable to the Former Building 7 Sump and Building 7 Lobe Source Area

The source area contains thin zones of residual and free-phase DNAPL that are primarily present in relatively deep (20 to 35 feet bgs) horizons of the Mixed Unit. Dissolved groundwater concentrations have been controlled in recent years by the balance between continued dissolution of COCs into groundwater, flushing of treated groundwater through the saturated zone, and changes in operations of the thermally enhanced SVE pilot test. Since COCs are present both in the dissolved phase in the groundwater and as residual and/or free-phase DNAPL, all retained alternatives listed in **Tables 4.2.3-1 and 4.2.3-2** (for soil and groundwater, respectively) were evaluated. The results of the evaluation are provided in **Table 4.3.4-4** and discussed below.

No Action

No action for the Building 7 lobe source area would consist of termination of all groundwater monitoring activities and stopping extraction and recirculation of groundwater from the Building 7 Groundwater Collection Trench. Soil and groundwater COC concentrations would remain above both target risk-based and regulatory-based MCSs for the foreseeable future. These conditions would require establishment of Institutional Controls to protect human health. Dissolution of COCs into groundwater would increase the rate of migration of dissolved COCs from the source area into the core area. In addition, this alternative would likely be

Table 4.3.4-4. Evaluation of Corrective Measures Alternatives, Former Building 7 Sump and Building 7 Lobe Source Area

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration (c)	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (d)	Regulatory Agency Acceptance	Community Concerns
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	no/no	no	no	yes	1	1	1	4	1	1
Institutional Controls	yes/no	no	no	yes	2	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	yes	yes	4	2	4	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/no	no	no	yes	1	1	1	3	4	3
Chemical Oxidation	yes/yes	unknown	na	yes	3	3	3	3	5	5
Enhanced bioremediation	yes/yes	no	no	yes	1	1	1	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	no	na	yes	3	2	2	3	4	4
Thermally Enhanced Dual Phase Extraction	yes/yes	unknown	yes	yes	3	4	2	3	5	5
Soil Containment – Capping, Solidification, Stabilization	yes/no	no	no	no	1	1	1	3	1	1
Excavation and Offsite Disposal	yes/yes	yes	yes	yes	5	5	5	2	5	4
Soil Mixing	yes/yes	unknown	yes	yes	3	3	2	2	5	5
Soil Mixing and Chemical Oxidation	yes/yes	yes	yes	yes	4	4	4	2	5	5

(a) Level of Compliance Ranking

1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance

1. None
2. Low
3. Partial
4. Moderate
5. High

(c) na; not applicable

(d) relative cost from 1 (high) to 5 (low)

unacceptable to the regulator agencies and the community. This alternative is not protective of human health and the environment and is therefore not recommended.

Monitored Natural Attenuation

COCs are present in the source area both as DNAPL and sorbed to the soil matrix at concentrations that will result in continued dissolution of COCs into groundwater. Until continued dissolution of COCs into the groundwater can be prevented, MNA would not be effective. In addition, even if dissolution were prevented, a considerable amount of time would be required for MNA to be effective, if it could be effective at all, given the high concentrations of COCs in the groundwater. MNA is not protective of human health and the environment and is therefore not recommended.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

Groundwater capture by itself is not an effective technology for reducing groundwater COC concentrations in the source area, primarily because of the presence of DNAPL in the saturated zone. However, containment of source area COCs would likely help expedite remediation of the downgradient core area. This alternative is not effective by itself in protecting human health or attaining MCSs and is therefore not recommended, except if used in combination with groundwater flushing, as described below.

Permeable Reactive Barrier/Funnel & Gate

This alternative is not effective in protecting human health or attaining MCSs in the source area due to the high concentrations of COCs currently present in the groundwater, and is therefore not recommended.

Chemical Oxidation

The effectiveness of in situ chemical oxidation for remediation of the source area is not known and would require pilot testing prior to any full-scale implementation. It was not possible to pilot-test this technology due to the ongoing thermally enhanced SVE pilot test being conducted in the small source area. In situ chemical oxidation is generally not effective in low permeability materials such as the Mixed Unit where the COCs are primarily present in the source area. Pilot testing of this technology in the low permeability Building 51L Groundwater Solvent Plume source area and Building 71B plume source area was not effective. For these reasons, chemical oxidation is not recommended.

Enhanced Bioremediation

Based on the results of an enhanced bioremediation pilot test (methanotrophic treatment technology pilot test) that was conducted in the Building 7 lobe core area, enhanced bioremediation would not be an effective technology in the source area. The pilot test was not effective in delivery of the enhancing agents to the source solvents in the low permeability/heterogeneous Mixed Unit where it was tested. Similar results would be expected in the source area, where the COCs are also primarily present in the Mixed Unit. Enhanced bioremediation is therefore not recommended.

Soil Flushing and Groundwater Extraction

Treated groundwater has been extracted from the Building 7 Groundwater Collection Trench and periodically injected into the Former Building 7 sump excavation since 1997. This source area flushing has resulted in decreases in soil COC concentrations in soil beneath the injection area, and decreases in groundwater concentrations to levels below target risk-based MCSs. Although groundwater concentrations have remained below target risk-based MCSs without flushing for almost a year, the data are insufficient to assess whether the groundwater concentration reductions will be permanent. Given the presence of DNAPL in the saturated zone, COC concentrations in groundwater would likely rebound to levels well above the target risk-based MCSs if groundwater capture and flushing were terminated. Therefore, although this technology can temporarily reduce concentrations below target risk-based MCSs, it is reliant on

continued operation to maintain these levels. Therefore, this technology is recommended only as a temporary control measure until other alternative(s) can permanently reduce COC concentrations to the required levels.

Soil Vapor Extraction and Thermally Enhanced Dual Phase Extraction (DPE)

The effectiveness of soil vapor extraction (SVE) is controlled by both contaminant volatility and subsurface vapor flow. In low permeability soils and in soils with high moisture contents, such as the Mixed Unit, flow rates adequate to remove contaminants cannot be achieved by SVE alone. Thermal heating, in combination with dewatering, dries the soil, thereby increasing the effectiveness of an SVE system. This technology has been effectively pilot-tested in the Mixed Unit in the Building 7 lobe source area, where over 700 kg of contaminant mass have been removed from the extracted soil vapor.

Although the system was installed as a pilot test, it is appropriately designed and located to continue removing contaminant mass from the source area; however, it is not known whether continued operation of this system will reduce COC concentrations below target risk-based MCSs. Once the contaminant mass removed by the system approaches an asymptotic level, the need for further corrective measures would be assessed by 1) collecting confirmation soil samples to compare to the MCSs and 2) comparing groundwater concentrations to the MCSs after any rebound has occurred. If further corrective measures are required to attain MCSs, either the system could be modified or expanded (e.g., installing additional heater or DPE wells), or an alternate technology (i.e., excavation and offsite disposal) could be implemented. A benefit of this alternative is that except for any system expansion costs, there would be no added cost for installation. Thermally enhanced DPE is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe source area using the decision factors shown in **Table 4.3.4-4**.

Soil Containment

Containment can be somewhat effective in protecting human health in the short term, but less effective in the long-term. Capping would not prevent the continued dissolution of COCs into the groundwater and subsequent downgradient migration. This alternative would not

achieve MCSs and would likely be unacceptable to the regulatory agencies or the community. For these reasons containment is not recommended.

Excavation and Offsite Disposal

Excavation of soil beneath and adjacent to the Former Building 7 Sump was conducted as an ICM in 1995. The excavation was completed by drilling large-diameter borings. A similar method is proposed for any additional source removal, because of the depth of excavation that would be required. Since relatively small volumes of residual soil contamination can result in continuing impacts to groundwater, this method would be modified to provide sufficient overlap of the auger holes so that all of the contaminated soil could be removed. Such a modification would likely involve drilling an initial set of spaced auger holes, backfilling them with a cement grout mixture, then drilling a second set of intervening auger holes, which partially overlapped the original holes.

The extent of any excavation would not be determined until post-pilot test soil samples are collected and compared to MCSs. Therefore, prior to excavation, soil samples will be collected to determine the extent of excavation that would be required. Post-excavation groundwater concentrations would likely decline to levels below target risk-based MCSs, but would probably remain above regulatory-based MCSs, since low levels of soil contamination in equilibrium with dissolved groundwater COCs would continue to be present in groundwater adjacent to the excavated area. Excavation and offsite disposal is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe source area using the decision factors shown in **Table 4.3.4-4**.

Soil Mixing

Soil mixing consists of using drilling equipment to break up the soil and increase the permeability, generally simultaneously with vapor extraction to remove volatilized contaminants. The method has been used in conjunction with injection of chemical reagents (e.g., oxidants), to destroy contaminants, or chemical reagents combined with grouts to stabilize contaminants. Injection of chemical oxidants, as described under Chemical Oxidation above, would likely increase the reliability and effectiveness of this method.

If implemented in the plume source area, this method would be used to break up and mix the low permeability Mixed Unit with the overlying higher permeability Moraga Formation. This would increase the permeability and allow flushing/extraction of the contaminants. Since thermally enhanced SVE was being pilot tested in the relatively small plume source area, it was not possible to pilot test this technology. Soil mixing is an implementable technology for the plume source area, but the effectiveness of this technology is not known. Excavation is preferred to soil mixing in the source area since excavation would be effective and the cost of soil mixing would be higher than the costs of excavation, given the small source area and the need for pilot testing soil mixing prior to implementation. Soil mixing is therefore not recommended.

Summary of Former Building 7 Sump and Building 7 Lobe Source Area Corrective Measures Implementation Strategy

The initial remediation objectives for the source area of the Building 7 lobe of the Old Town Groundwater Plume source area are to: 1) remove any residual or free-phase DNAPLs that continue to result in dissolution of COCs into groundwater; 2) decrease vadose zone soil COC concentrations below target risk-based MCSs; and, 3) decrease groundwater COC concentrations below target risk-based MCSs. The corrective measures alternatives that were identified as likely to meet these objectives are thermally enhanced DPE and excavation with offsite disposal.

A cost comparison of the two alternatives under consideration (thermally enhanced DPE and excavation and offsite disposal) is provided in **Appendix C**. Expansion of the thermally enhanced DPE system, assuming the need for two additional heater wells and two additional DPE wells, would cost approximately \$94,700. Operation and maintenance costs of the system would be approximately \$118,500 per year. The estimated cost and net present value for excavation, offsite disposal, and restoration of an area of 200 square feet to a depth of 60 feet bgs (444 cubic yards) is approximately \$569,200.

The estimated cost of expansion and continued operation of the thermally enhanced DPE system would exceed the cost of excavation with offsite disposal within approximately 5 years of DPE operation. Based on the operational history of the thermally enhanced DPE pilot-test system, 5 years would not be sufficient time to meet target risk-based MCSs. In addition, the level of compliance ranking of the other decision factors listed in **Table 4.3.4-4** (long-term

reliability and effectiveness, the short term effectiveness, and the reduction in toxicity, mobility, or volume) for excavation and offsite disposal are greater than those for thermally enhanced DPE. Therefore, excavation with offsite disposal is recommended as the preferred alternative.

After confirmation sampling shows that the three initial source area remediation objectives have been met, the plume source area will be managed in accordance with the strategy described below for the plume periphery. After completion of the excavation, operation of the Building 7 groundwater collection trench would be discontinued, except as necessary to remediate the plume core. If the objectives have not been met, then the source zone will be managed in accordance with the strategy described below for the plume core.

Alternatives Applicable to the Building 7 Lobe Core Area

The core area contains COCs primarily dissolved in the groundwater. In addition, COCs sorbed to low permeability soils as a result of equilibrium partitioning with the groundwater constitute a continuing source of groundwater contamination. Wells in the core area generally cannot produce more than 200 gpd and therefore risk-based MCSs are the applicable cleanup levels. The presence of DNAPL is uncertain; however, the evidence indicates that some DNAPL may be present, particularly in the upgradient core area near the source. Therefore, retained alternatives listed in both **Tables 4.2.3-1 and 4.2.3-2** (for soil and groundwater, respectively) were evaluated. The results of the evaluation are provided in **Table 4.3.4-5** and discussed below.

No Action

No action in the Building 7 lobe core would consist of termination of all groundwater monitoring activities, stopping operation of the Building 53/58 slope DPE system and the Building 58 east groundwater collection trench, and terminating injection and extraction of groundwater from wells in the core area. Groundwater concentrations would remain at levels above target risk-based

Table 4.3.4-5. Evaluation of Corrective Measures Alternatives, Building 7 Lobe Core

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (c)	Regulatory Agency Acceptance	Community Concerns
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	no/no	no	no	yes	1	1	1	4	1	1
Institutional Controls	yes/no	no	no	yes	2	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	yes	Yes	3	2	3	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/no	no	no	yes	1	1	1	3	4	3
Chemical Oxidation	yes/yes	unknown	yes	yes	3	3	3	3	5	5
Enhanced bioremediation	yes/yes	no	no	yes	1	1	1	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	yes	yes	yes	3	4	4	4	4	4
Thermally Enhanced Dual Phase Extraction	yes/yes	unknown	yes	Yes	3	4	2	2	5	5
Excavation and Offsite Disposal	yes/yes	yes	yes	yes	5	5	5	1	5	4
Soil Mixing	yes/yes	unknown	yes	Yes	2	2	2	1	5	5
Soil Mixing and Chemical Oxidation	yes/yes	yes	yes	yes	3	4	3	1	4	4

(a) Level of Compliance Ranking

1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance

1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

and regulatory-based MCSs for the foreseeable future. These conditions would require establishment of Institutional Controls to protect human health. Migration of dissolved COCs from the plume core into the plume periphery might result in concentrations of groundwater COCs in the periphery exceeding risk-based levels. This alternative is not protective of human health and the environment and would likely be unacceptable to the regulators and the community, and is therefore not recommended.

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997. As part of this study, geochemical parameters were measured in several wells located in the Building 7 lobe core area. Concentrations of geochemical indicator parameters, particularly the relatively high dissolved oxygen concentration, were not favorable for natural degradation processes. MNA is not protective of human health and the environment and is therefore not recommended.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies or the community, and is therefore not recommended.

Groundwater Containment/Capture

Groundwater capture by itself is not an effective technology for reducing groundwater COC concentrations in the core area, primarily because of the extremely long time required for contaminants to diffuse from the low permeability Mixed Unit and the low groundwater velocities. This technology has been implemented within the plume core to effectively control migration of COCs from high concentration areas in the core into lower concentration areas of the core and periphery. This alternative is not effective by itself in protecting human health or

attaining MCSs and is therefore not recommended as a corrective measures alternative, unless it is used in combination with groundwater flushing, as described below.

Permeable Reactive Barrier/Funnel & Gate

This alternative is not effective in protecting human health or attaining MCSs in the source area due to the high concentrations of COCs currently present in the groundwater, and is therefore not recommended.

Chemical Oxidation

The effectiveness of chemical oxidation for remediation of the core area is not known and would require pilot testing prior to any full-scale implementation. In situ chemical oxidation is generally not effective in low permeability and/or heterogeneous materials such as the Mixed Unit, so the likelihood that it would be effective is considered to be low. However, if pilot testing showed that delivery of reagents to the impacted pore space could be ensured, then this technology could potentially be effective. Therefore, the method is retained for further evaluation in the summary section below because of the limited number of technologies potentially effective in the core area. Implementation of this method would require numerous closely spaced injection points (typically on the order of 3 to 5 feet spacing). Chemical oxidation is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe core area using the decision factors shown in **Table 4.3.4-5**.

Enhanced Bioremediation

Based on the results of an enhanced bioremediation pilot test (methanotrophic treatment technology pilot test), enhanced bioremediation is not an effective technology. The pilot test was not effective in delivery of the enhancing agents to the source solvents in the low permeability/heterogeneous Mixed Unit in the source area where it was tested. Enhanced bioremediation is therefore not recommended. The technology may be effective as part of a long-term strategy for the plume core once concentrations have been reduced to levels that are more conducive to natural attenuation processes.

Soil Flushing and Groundwater Extraction

Given the high concentrations of dissolved COCs in the plume core, and the tendency of clay-rich units such as the Mixed Unit to adsorb COCs from the groundwater, flushing of a large number of pore volumes of clean groundwater would be needed to reduce groundwater COC concentrations below the target risk-based MCSs. The soil flushing pilot test being conducted in the core area has resulted in decreased concentrations of COCs in several wells, indicating that this method may be effective in reducing concentrations below risk-based levels. The rate of concentration reduction is highly dependent on the permeability of the rocks, however, and insufficient data are currently available to estimate the time required for compliance with target risk-based MCSs. Groundwater extraction and flushing is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe core area using the decision factors shown in **Table 4.3.4-5**.

Thermally Enhanced Dual Phase Extraction (Heater Test)

Thermally enhanced dual phase extraction is primarily suitable for unsaturated soils with high concentrations of residual or free-phase DNAPL. Therefore, this method has poor applicability to the core of the Building 7 lobe, where contamination is primarily associated with groundwater flowing in the saturated zone. In addition, the capital, operations and maintenance costs for the relatively small-scale system in the source area was estimated at \$629,800 for expansion of a preexisting system and the initial five years of operation. This cost does not include the primary capital costs that would be associated with installation of a new system. The operations and maintenance costs for the much larger core area would be at least an order of magnitude greater, and capital costs would also need to be applied to this area. Thermally enhanced DPE is not recommended due to both the poor applicability of the method and the large costs of implementation.

Excavation and Offsite Disposal

Excavation of the low permeability rocks of the Mixed Unit along with the contaminated groundwater contained within them would likely reduce contaminant concentrations below target risk-based MCSs. However, the required extent of excavation adjacent to the Advanced Light

Source (ALS) could have severe impacts on of ALS operations. Excavation and offsite disposal is retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe source area using the decision factors shown in **Table 4.3.4-4**. The relatively steep slope requiring excavation, the depth of excavation required, and the sensitive structures at both the top and base of the slope would require extremely costly excavation measures.

Soil Mixing

Soil mixing would be used to break-up and mix the low permeability Mixed Unit with the overlying higher permeability Moraga Formation. This would increase the permeability and enhance flushing/extraction of groundwater COCs or enhance injection of chemical oxidant reagents. The method has been used in conjunction with injection of chemical reagents (e.g., oxidants), to destroy contaminants, or chemical reagents combined with grouts to stabilize contaminants. Injection of chemical oxidants, as described under Chemical Oxidation above, would likely increase the reliability and effectiveness of this method. Prior to implementing soil mixing, pilot testing would be required to assess its effectiveness and evaluate whether injection of chemical reagents would increase its effectiveness.

Since soil mixing reduces the density of the subsurface materials, a concern with the technology would be its impact on the stability of the slope below the ALS and mitigation measures that might be required after the mixing is completed. The cost of implementing soil mixing would be considerably less than the cost for either chemical oxidation or excavation, since it would basically consist of a combination of those two technologies (less disposal costs). Soil mixing is therefore not recommended because of implementability concerns and cost. However, if it can be shown that small “hot spots” of low permeability, highly impacted zones within the core remain after implementation of another technology, such an approach may be viable for locally increasing the permeability of those areas to enhance soil flushing.

Summary of Building 7 Lobe Core Corrective Measures Implementation Strategy

The initial remediation objectives for the core area of the Building 7 lobe of the Old Town Groundwater Solvent Plume are to: 1) decrease groundwater COC concentrations below

target risk-based MCSs; and, 2) prevent migration of COCs in groundwater at concentrations above risk-based levels into the periphery. The alternatives that were identified as likely to meet these objectives are chemical oxidation, excavation with offsite disposal, and groundwater extraction/flushing. In addition, soil mixing was considered but rejected because of slope stability concerns and since the cost would be considerably higher than the other three technologies under consideration.

A cost comparison of the three alternatives under consideration (chemical oxidation, excavation with offsite disposal, and groundwater extraction/flushing) is provided in **Appendix C**. The cost for application of chemical oxidation is estimated at \$4,150,000. The cost for groundwater extraction and flushing is estimated as \$22,000 in capital costs for system expansion and \$62,000 per year for operation and maintenance. Net present value for capital, operation, and maintenance costs is estimated at \$1,193,400, assuming 30 years of operation. The base cost for excavation and offsite disposal is estimated at \$6,180,000.

Based only on cost, groundwater extraction and flushing would be the recommended alternative. In addition, the level of compliance rankings of the other decision factors listed in **Table 4.3.4-5** (long-term reliability and effectiveness, the short-term effectiveness, and the reduction in toxicity, mobility, or volume) for groundwater extraction and soil flushing are higher than those for chemical oxidation. Although the level of compliance rankings for excavation and offsite disposal are somewhat higher than those for groundwater extraction and flushing, the estimated \$5,000,000 cost differential outweighs the other factors. Groundwater extraction and flushing is therefore recommended as the preferred alternative, particularly since the estimated cost for excavation does not consider potentially significant impacts on ALS operations.

If groundwater COC concentrations in part or the entire plume core are reduced to levels below target risk-based MCSs, then those areas will be managed according to the strategy described below for the plume periphery.

Alternatives Applicable to the Building 7 Lobe Periphery Area

The periphery area contains groundwater COCs at concentrations below target risk-based MCSs but above regulatory-based MCSs (i.e., MCLs), and includes areas that are primarily

downgradient or crossgradient from the core area. Many of the wells in the periphery area can produce more than 200 gpd and therefore regulatory-based MCSs are the applicable cleanup levels. As a result of natural attenuation, the hydrogeologic setting, and/or ongoing groundwater capture, groundwater containing COCs at detectable concentrations has not been migrating beyond the currently defined plume boundary. As corrective measures reduce groundwater concentrations in the Building 7 lobe source and core areas to levels below target risk-based MCSs, those areas will be controlled using the same strategy for the periphery area described in this section.

Since COCs in the periphery area are present primarily in groundwater, with only a negligible fraction present as sorbed soil COCs in equilibrium with groundwater, only retained alternatives listed in **Table 4.2.3-2** (potential corrective measures alternatives for groundwater) are evaluated. The results of the evaluation are provided in **Table 4.3.4-6** and discussed below.

No Action

No-action in the Building 7 lobe periphery would consist of terminating all groundwater monitoring activities and stopping operation of the Building 58 West and Building 58 East Groundwater Collection Trenches and the Building 53/58 Slope Dual Phase (groundwater and soil vapor) Extraction System. Groundwater concentrations would remain at levels above regulatory-based MCSs for the foreseeable future, although natural degradation processes would likely result in continued decreases in COC concentrations at some locations. In addition, termination of groundwater extraction at the leading edge of the lobe east of Building 58 could degrade downgradient groundwater quality. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community. It also does not comply with regulatory requirements and is therefore not recommended.

Monitored Natural Attenuation

Studies of geochemical and biological parameters indicative of the potential for natural degradation of COCs were conducted within the plume area in 1997 and 2003. Data from wells monitoring the downgradient portion of this area (MW58A-94-14 and MW58-95-18) suggest that ongoing natural attenuation is occurring. The rate of natural attenuation is expected to

Table 4.3.4-6. Evaluation of Corrective Measures Alternatives, Building 7 Lobe Periphery

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (c)	Regulatory Agency Acceptance	Community Concerns
No Action	yes/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	no	yes	3	3	2	4	3	1
Institutional Controls	yes/no	no	no	yes	3	1	3	4	4	2
Groundwater Containment/Capture	yes/yes	no	yes	yes	3	2	3	3	4	4
Permeable Reactive Barrier/Funnel & Gate	yes/yes	no	yes	yes	3	2	3	2	4	3
Chemical Oxidation	yes/yes	unknown	yes	yes	3	3	3	1	5	5
Enhanced bioremediation	yes/yes	unknown	no	yes	1	1	1	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	yes	yes	yes	3	3	3	4	4	4

(a) Level of Compliance Ranking

1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance

1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

increase in most areas of the periphery as corrective measures in the source and core areas reduce COC concentrations in the upgradient groundwater.

MNA is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe periphery area using the decision factors shown in **Table 4.3.4-6**.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

Groundwater containment/capture can effectively control migration of COCs from the periphery into uncontaminated areas downgradient from the Building 7 lobe to comply with regulatory requirements. Groundwater capture has been effective at controlling downgradient migration of the leading edge of the Building 7 lobe, and should continue until it can be shown that termination of the technology does not result in detectable concentrations of COCs in downgradient compliance wells.

Permeable Reactive Barrier /Funnel & Gate

A permeable reactive barrier or funnel and gate might also control migration of COCs from the periphery into uncontaminated areas to comply with regulatory requirements in areas downgradient from the Building 7 lobe. However, since the groundwater collection trench has been installed as an ICM and groundwater treatment systems are already in place, this alternative would have added costs. In addition, the effectiveness of a permeable reactive barrier is not known. This alternative is therefore not recommended.

Chemical Oxidation

The effectiveness of in situ chemical oxidation for remediation of the periphery is not known and would require pilot testing prior to any full-scale implementation. In situ chemical oxidation is generally not effective in low permeability and/or heterogeneous materials such as the Mixed Unit and Orinda Formation. Generally, chemical oxidation is applied to areas that have high COC concentrations, and is not applicable to broad areas of low level contamination, such as the Building 7 lobe periphery, due to the high costs of reagent injection, the need for close spacing of injection points, and because reagent chemistry does not persist during groundwater migration. The cost for conducting chemical oxidation of the plume core was estimated to be approximately \$4,150,000 (**Appendix C**), and would be higher for the plume periphery due to the larger area that would require treatment. For these reasons, chemical oxidation is not recommended.

Enhanced Bioremediation

Available data indicate that natural biodegradation of COCs is occurring in the periphery area, and that enhancement of bioremediation may not be necessary. However, it is possible that some enhanced bioremediation methods may be effective for expediting the process in some parts of the periphery. Enhanced bioremediation is recommended for consideration only if MNA by itself becomes ineffective.

Soil Flushing and Groundwater Extraction

Available data indicate that DNAPL is not present in the plume periphery, although very low concentrations of sorbed COCs in equilibrium with dissolved groundwater COCs are likely to be present. Therefore, groundwater flushing may result in permanent reductions of COC concentrations that are maintained with minimal “rebound” after cessation of flushing.

As described above, a soil flushing pilot test is currently being conducted in the plume core, and results indicate that this technology has been effective in decreasing COC concentrations. This technology would likely be even more effective in the plume periphery, which has even lower initial dissolved COC concentrations. Additional injection/extraction wells/trenches could be installed to flush the plume periphery. Soil flushing with groundwater

extraction is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe periphery area using the decision factors shown in **Table 4.3.4-6**.

Summary of Building 7 Lobe Periphery Corrective Measures Implementation Strategy

The remediation objectives at the Building 7 lobe periphery are to: 1) ensure that groundwater COCs do not migrate into uncontaminated areas; and, 2) decrease groundwater COC concentrations below regulatory-based MCSs. The corrective measures alternatives that were identified as likely to meet these objectives are MNA, groundwater capture, enhanced bioremediation, and soil flushing with groundwater extraction.

Groundwater capture should continue at the leading edge of the Building 7 lobe to meet remediation objective (1) above until it can be shown that termination of groundwater extraction does not result in detectable concentrations of COCs in downgradient compliance wells.

A combination of MNA and soil flushing and groundwater capture is recommended to meet objective (2) above. The level of compliance rankings for the decision factors listed in **Table 4.3.4-5** (long-term reliability and effectiveness; the short-term effectiveness; the reduction in toxicity, mobility, or volume; and cost) for these two alternatives are similar. Since available data indicate that natural attenuation is resulting in concentration reductions at the downgradient edge of the Building 7 lobe, MNA is the recommended alternative for this area. Soil flushing is the recommended alternative for the other areas of the periphery where evidence for MNA is currently absent.

4.3.5. Building 52 Lobe of the Old Town Groundwater Solvent Plume

A general description of the Old Town Groundwater Solvent Plume is given in **Section 4.3.3**. As described in that section, the Old Town plume consists of three coalescing lobes (Building 7 lobe, Building 25A lobe, and Building 52 lobe) of halogenated non-aromatic hydrocarbons derived from distinct sources (**Figure 4.3.4-1**). The Building 52 lobe extends northwestward from the area east of Building 52 to Building 46, where the contaminated groundwater is captured by the Building 46 subdrain (**Figure 4.3.5-1**).

The distribution of elevated VOC concentrations in the Building 52 lobe indicates that the source of groundwater contamination was located east of Building 52A. Groundwater and soil sampling conducted in 1998 and 2000 to characterize the location, and magnitude and extent of COCs in this area indicated that a source of the lobe was likely spills in the vicinity of the paved area east of Building 52A. An ICM was conducted in 2001 that consisted of excavation of contaminated soil from this area. In addition, a soil flushing pilot test was initiated near the source area in May 2003.

4.3.5.1 Current Conditions

Geology and Hydrogeology

Bedrock consists primarily of relatively permeable volcanic rocks of the Moraga Formation, up to 80 feet thick, overlying the low permeability Orinda Formation. The water table lies at approximately 50 to 70 feet below ground surface throughout most of the lobe, although it shallows to approximately 7 feet bgs at the base of the steep slope east of Building 46, where the toe of the lobe is intercepted by the Building 46 subdrain. The groundwater gradient is westward to northwestward (**Figure 4.3.4-9**). Wells screened within the Moraga Formation in the Building 52 lobe are generally able to produce more than 200 gpd (**Figure 4.3.5-1**). Groundwater flow modeling has been conducted for the Old Town Plume, including the Building 52 Lobe using the ITOUGH2 code (Zhou and others, 2003; Preuss and others, 1999). The modeling, along with slug test data, was used to estimate rock physical characteristics (i.e., hydraulic conductivity and effective porosity) based on matching of seasonal variations in

groundwater elevations. The model results indicate hydraulic conductivity values of approximately 10^{-5} meters per second and effective porosity values of approximately 0.04 within the Moraga Formation of the Building 52 lobe. Modeled flow velocities based on these values are typically in the range of 3 to 6 meters per day (10 to 20 feet per day), which are substantially greater than velocities estimated for other parts of Berkeley Lab. Modeled travel time estimates indicate that particles located at the head of the Building 52 lobe would reach the toe of the lobe in 28 to 65 days (**Appendix D**). Modeling results also suggest that groundwater generally flows westwards towards Building 53, and then turns northwestwards towards Building 46

Groundwater Contamination

The principal Building 52 lobe constituents are halogenated non-aromatic VOCs that were used as cleaning solvents, including PCE and carbon tetrachloride, and their degradation products (e.g., TCE 1,1-DCE, cis-1,2-DCE, and chloroform). Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.5-1**, where the maximum detected concentrations are compared to the target risk-based MCSs.

Groundwater COC Trends

Concentration trends for total halogenated non-aromatic VOCs detected in wells monitoring the Building 52 lobe are shown on **Figure 4.3.5-2**. An overall long-term decline in concentrations was observed from approximately 1995 through 1999 in the core of the lobe (MW52-95-2B), but concentrations have since remained relatively stable. A decreasing trend was also observed in wells monitoring the downgradient area of the lobe (MW27-92-20 and MW46-93-12), primarily between 1995 and 1997.

Table 4.3.5-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 52 Lobe of the Old Town Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
TCE	87.8	5	1,594
PCE	34*	5	343
carbon tetrachloride	13.9	0.5	27
cis-1,2-DCE	44.3	6	98,405

* In August 2003, PCE concentrations of 537 and 410 µg/L were detected in two wells within the plume, but are inconsistent with all other results from these wells and are therefore not considered to be representative of groundwater conditions.

The relative proportions of plume constituents vary with distance downgradient from the source area, with PCE becoming less abundant in comparison to TCE and DCE, indicating that degradation occurs during plume migration. The relative proportions of the primary COCs in the PCE degradation pathway (PCE, TCE, cis-1,2-DCE, and 1,1-DCE) are shown on **Figure 4.3.5-3** (source area well), **Figure 4.3.5-4** (midplume well), and **Figure 4.3.5-5** (downgradient well). As shown on the figures, the relative proportions of these constituents at each well location have changed relatively little over time. This indicates that the rate of degradation in the downgradient areas does not greatly exceed the rate of dissolution of COCs from residual soil contamination and migration from the source area.

The relative proportions of COCs in the carbon tetrachloride degradation pathway (carbon tetrachloride and chloroform) are shown on **Figure 4.3.5-6** (source area well), **Figure 4.3.5-7** (midplume well), and **Figure 4.3.5-8** (downgradient well). Although the total concentration of carbon tetrachloride and chloroform has gradually declined, their relative proportions have shown no consistent trend, suggesting that degradation is not an important factor in reducing concentrations of these COCs within the lobe.

An ICM using soil flushing technology was initiated for the Building 52 Lobe in May 2003. This ICM has comprised injection of treated groundwater into groundwater monitoring wells MW52-98-8B and MW52-98-9 in the upgradient portion of the lobe. An approximately 50% reduction in COC concentrations was observed in monitoring well MW52-95-2B, located

downgradient from the injection wells, over three months of pilot test operation (**Figure 4.3.5-2**). The decrease indicates that flushing is an effective method for reducing groundwater COC concentrations, at least in the short-term.

Soil Contamination

Soil samples were collected in 2000 from twenty shallow (approximately 10-feet deep) borings to help locate the source of the contamination detected in groundwater east of Building 52A. Up to 5 mg/kg total halogenated VOCs, consisting predominantly of PCE with lesser amounts of TCE and cis-1,2-DCE, were detected in soil samples collected from borings close to the monitoring wells with the highest groundwater concentrations. In 2001, the area of soil contamination east of Building 52A was excavated to a depth of approximately 9 feet as an ICM (**Figure 4.3.5-9a** and **Figure 4.3.5-9b**). The maximum concentrations of halogenated VOCs detected in residual soil from the excavation area were below the target risk-based MCSs except for two samples that contained PCE exceeding its MCS and one sample that contained cis-1,2-DCE exceeding its MCS. However, the 95% UCLs for both PCE and cis-1,2-DCE in this area were less than the target risk-based MCSs (**Appendix H**) indicating that representative COC concentrations are lower than levels of concern.

Evidence of DNAPL and Residual Soil Contamination

Maximum concentrations of COCs detected in soil samples collected in the Building 52 lobe area are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**. Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs. This lack of evidence for the presence of DNAPLs is corroborated by the decline in total concentrations of halogenated VOCs in upgradient areas of the lobe observed from approximately 1995 to 1999.

The lack of continuing declining concentration trends (excluding declines that have been a direct result of soil flushing) and the absence of changes in relative proportions of COCs in groundwater indicate that residual soil contamination is probably present at the upgradient edge of the lobe.

4.3.5.2 *Conceptual Model*

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 52 lobe of the Old Town Groundwater Solvent Plume:

- There is no evidence suggesting the presence of DNAPL. The only residual soil contamination detected in the vadose zone consists of relatively low concentrations of contamination beneath the ICM excavation that are less than regulatory-based soil MCSs.
- Past declining concentration trends in groundwater in the upgradient area of the lobe suggest that the mass of residual soil contamination available to impact groundwater has declined in the past. However, the cessation of significant concentration declines and the lack of evidence for degradation of COCs at the head of the lobe indicate that low levels of residual contamination in equilibrium with dissolved groundwater COCs probably remain within the saturated zone. Therefore, corrective measures for the lobe should be based on the remediation of dissolved-phase COCs and low level saturated zone residual soil contamination.
- The Building 52 lobe lies within an area where groundwater flows primarily through the relatively permeable rocks of the Moraga Formation. Continued groundwater flow may result in flushing of contaminants from the pore space of the Moraga Formation.
- Wells within the Moraga Formation in the Building 52 lobe are expected to have sustainable yields greater than 200 gpd, so regulatory-based MCSs are applicable.
- The Building 52 lobe is elongated along the direction of groundwater flow, consistent with advection being the predominant contaminant transport mechanism. The estimated groundwater velocity is roughly 10 to 20 feet per day in the Moraga Formation in this area.
- Spatial variations in plume chemistry suggest that degradation has been occurring during migration of constituents that are part of the PCE degradation pathway. The lack of temporal change in the relative proportions of COCs indicates that the plume has apparently reached a state of equilibrium where degradation rates are similar to rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. No evidence for degradation of carbon tetrachloride has been observed.
- Concentrations of COCs are above regulatory-based MCSs for groundwater, but are less than regulatory-based MCSs for soil and less than target risk-based MCSs for soil and groundwater.
- Initial results of the soil flushing pilot test indicate that this method may be effective at decreasing COC concentrations within the lobe.

4.3.5.3 *Evaluation of Retained Corrective Measures Alternatives*

Concentrations of groundwater COCs in the Building 52 lobe exceed regulatory-based MCSs for a number of COCs, but are well below target risk-based MCSs. Since well yield is greater than 200 gpd, regulatory-based MCSs are applicable.

As a result of ongoing capture of groundwater at a subdrain located east of Building 46 at the leading edge of the lobe, groundwater containing COCs at detectable concentrations has not been migrating beyond the currently defined plume boundary. Transfer of COCs to surface water could potentially occur through the storm drain system, if the extraction of water from the Building 46 subdrain were terminated. However, as a result of dilution and volatilization of COCs, the chemical concentrations would likely be below detectable levels at the outflow to the creek.

Since COCs are present primarily in groundwater, with only a negligible fraction present as sorbed soil COCs in equilibrium with groundwater and there is no indication of the presence of DNAPL, only retained technologies listed in **Table 4.2.3-2** (potential corrective measures technologies for groundwater) are evaluated. The results of the evaluation are provided in **Table 4.3.5-2** and discussed below.

Table 4.3.5-2. Evaluation of Corrective Measures Alternatives, Building 52 Lobe

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (c)	Regulatory Agency Acceptance	Community Concerns
No Action	yes/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	no	yes	2	2	1	4	1	1
Institutional Controls	yes/no	no	no	yes	3	1	3	4	4	2
Groundwater Containment/Capture	yes/yes	no	yes	yes	3	2	3	4	4	4
Permeable Reactive Barrier/Funnel & Gate	yes/yes	no	yes	yes	3	2	3	3	4	3
Chemical Oxidation	yes/yes	unknown	yes	yes	2	3	3	1	5	5
Enhanced bioremediation	yes/yes	unknown	no	yes	3	3	2	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	yes	yes	yes	3	3	4	3	4	4

(a) Level of Compliance Ranking

1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance

1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

No Action

No action for the Building 52 lobe would consist of terminating all groundwater monitoring activities and stopping extraction and treatment of water from the Building 46 subdrain, which intercepts the downgradient edge of the 52 lobe. Under this alternative, once extraction from the subdrain was halted, contaminated groundwater could enter the storm drain system and flow into North Fork Strawberry Creek, although as described above, the COC concentrations would likely be below levels of concern at the creek outfall. Groundwater concentrations would remain at levels above regulatory-based MCSs for the foreseeable future, although natural degradation processes would likely result in decreases in COC concentrations at some locations. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community. It also does not comply with regulatory requirements and is therefore not recommended.

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997. Geochemical parameters measured in well MW52-95-2B, located in the upgradient portion of the Building 52 lobe were not favorable for natural degradation processes. In particular, the dissolved oxygen concentration was substantially greater than the minimum concentration that is considered indicative of conditions under which reductive dechlorination of COCs can occur. However, observed ratios of parent-daughter compounds within the plume strongly suggest that degradation occurs during downgradient migration. As described above, the lobe has apparently reached a state of equilibrium where the degradation rates are similar to the rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. These observations indicate that MNA would not be an effective alternative unless concentrations of COCs in groundwater in the upgradient area were to be significantly reduced. Therefore, MNA should only be considered in combination with more aggressive remediation technologies.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

Groundwater capture has been effective at controlling downgradient migration of the leading edge of the Building 52 lobe and preventing the flow of contaminated water through the stormdrain system to North Fork Strawberry Creek. This technology should continue until it can be shown that termination of the technology does not result in detectable concentrations of COCs in downgradient compliance wells and it can be shown that COCs would not be detected at the outfall to North Fork Strawberry Creek.

Permeable Reactive Barrier /Funnel & Gate

A permeable reactive barrier or funnel and gate system might control migration of COCs into uncontaminated areas to comply with regulatory requirements in areas downgradient from the Building 52 lobe. However, since the subdrain and groundwater treatment systems are already in place, this alternative would have added costs. In addition, the effectiveness of these types of systems is not known. This alternative is therefore not recommended.

Chemical Oxidation

Generally, the chemical oxidation method is applied in areas that have high COC concentrations and is not applicable to broad areas of low-level contamination due to the high costs of reagent injection, the need for close spacing of injection points, and because reagent chemistry does not persist during groundwater migration. High COC concentrations or “hot spots” are not present in the Building 52 lobe area, so the technology is unlikely to be cost effective. In addition, the effectiveness of the technology for remediation of the Building 52 lobe is not known and would require pilot testing prior to any full-scale implementation. The cost for conducting chemical oxidation for the Building 52 lobe would be greater than that estimated for the smaller area

Building 7 lobe core, which was estimated to be approximately \$4,150,000 (**Appendix C**). Based on the high cost and unlikely effectiveness of this technology, it is not recommended.

Enhanced Bioremediation

Available data suggest that natural degradation is occurring in the Building 52 lobe area during downgradient migration of dissolved COCs. Therefore, the addition of enhancements might be effective in stimulating bioremediation of groundwater COCs, although the method would probably not be effective in the upgradient area of the lobe where high dissolved oxygen concentrations were measured. The technology may be effective as part of a long-term strategy for the Building 52 lobe; however, pilot test would need to be performed to evaluate its effectiveness. Enhanced bioremediation would not be implemented until groundwater COC concentrations in the upgradient lobe area have been reduced to levels that do not migrate to the downgradient area at concentrations above regulatory-based levels.

Soil Flushing and Groundwater Extraction

Available data indicate that DNAPL is not present in the Building 52 lobe, groundwater COC concentrations are relatively low, and the contamination is present in relatively permeable rocks. These characteristics indicate that soil flushing and groundwater extraction may be effective in reducing COC concentrations in the groundwater with minimal “rebound” after flushing is terminated.

After the first three months of operation of the soil flushing pilot test in the upgradient area of the Building 52 lobe, groundwater COC concentrations in MW52-95-2B, located close to the injection points, have been reduced by approximately 50%. Additional injection/extraction wells/trenches could be installed to remediate the areas of the Building 52 lobe beyond the pilot test area.

Summary of Building 52 Lobe Corrective Measures Implementation Strategy

The remediation objectives for the Building 52 lobe are to: 1) ensure that groundwater COCs at detectable concentrations do not migrate to surface water; 2) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs do not migrate into areas where concentrations are less than MCSs; and, 3) decrease groundwater COC concentrations below

regulatory-based MCSs. The remedial technologies that have been identified that may meet these objectives are groundwater capture, MNA, enhanced bioremediation, and soil flushing.

Groundwater capture using the Building 46 subdrain addresses remediation objectives (1) and (2) above. This technology should continue until it can be shown that termination of the technology does not result in detectable concentrations of COCs in downgradient compliance wells and at the outfall to North Fork Strawberry Creek. The system (Building 46 subdrain and groundwater treatment system) is already in place and operation and maintenance costs are relatively low.

In situ soil flushing has been identified as a potentially effective alternative to address remediation objective (3) above. Based on the initial soil flushing pilot test results, this technology may permanently reduce COC concentrations to regulatory-based MCSs, and therefore is recommended for full-scale implementation. If in situ soil flushing results in COC concentrations above the regulatory-based MCSs, MNA should be considered to further reduce the concentrations. As described above, the Building 52 lobe has apparently reached a state of equilibrium where the degradation rates are similar to the rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. Soil flushing may reduce COC concentrations sufficiently so that MNA becomes an effective alternative (i.e., the rate of degradation exceeds the rate of dissolution in the upgradient lobe area and migration). Enhanced bioremediation should be considered if MNA becomes ineffective.

4.3.6 Building 25A Lobe

The Old Town Groundwater Solvent Plume is discussed in **Section 4.3.3**. As described in that section, the Old Town plume consists of three coalescing lobes (Building 7 lobe, Building 25A lobe, and Building 52 lobe) of halogenated non-aromatic hydrocarbons derived from distinct sources (**Figure 4.3.4-1**). The Building 25A Lobe encompasses two subplumes of groundwater contamination, containing different suites of COCs, which are likely derived from different sources. The primary subplume contains TCE, 1,1-DCE and minor amounts of cis-1,2-DCE, and extends from the western portion of Building 25A westward to the eastern edge of Building 6 (**Figure 4.3.6-1**). This subplume contains over 200 ug/L total VOCs and is primarily present in rocks of the relatively low permeability Orinda Formation. The second subplume contains primarily PCE (approximately 20 µg/L maximum concentration), with lower concentrations of TCE and carbon tetrachloride. This subplume extends from east of Building 25A to south of Building 25 (**Figure 4.3.6-2**), roughly coincident with the body of permeable Moraga Formation rocks that underlies that area

Based on the concentrations of COCs in the groundwater, the source area for the western subplume is located near the western end of Building 25A. From approximately 1996 to 1998, soil and soil gas sampling were conducted in that area; however, no specific source was located. An ICM was started in 2002 to flush contaminants from the soil in the source area. The ICM consists of injection of treated groundwater into a shallow infiltration trench located between Building 25A and Building 44A and extraction of the injected water from a downgradient trench west of Building 25A and from well MW25A-98-3 north of Building 25A. Extraction, treatment, and recirculation of water from the trench were started in April 2002.

4.3.6.1 Current Conditions

Geology and Hydrogeology

The Building 25A lobe extends both southwards and westwards from Building 25A, with the highest COC concentrations detected in wells at the west end of the building. Bedrock beneath the Building 25 lobe area consists of relatively permeable volcanic rocks of the Moraga

Formation overlying low permeability rocks of the Orinda Formation. Two large bodies of Moraga Formation rocks occupy depressions in the upper contact of the Orinda Formation. One is oriented north-south beneath Building 25 and the eastern part of Building 25A, while the other is located beneath Buildings 5 and 16. Due to the large contrast in hydraulic conductivity between these two units, the geometry of these bodies has a significant effect on groundwater flow in the lobe. Groundwater is present in both the Moraga Formation and Orinda Formation. As shown on **Figure 4.3.6-3**, wells screened within the Moraga Formation, and within a zone of relatively permeable Orinda Formation rocks in the area north of Building 25A are generally able to produce more than 200 gpd. However wells screened within the Orinda Formation are generally unable to produce more than 200 gpd.

The water table is generally 20 to 30 feet bgs in the vicinity of Buildings 25A, 5 and 16, but deepens to approximately 80 feet bgs south of Building 25. Groundwater gradient and flow directions are generally westward southward and eastward, radially away from Building 25A (**Figure 4.3.4-9**).

Groundwater flow modeling has been conducted for the Old Town Plume, including the Building 25A lobe using the ITOUGH2 code (Zhou and others, 2003; Preuss and others, 1999). The modeling, along with slug test data, was used to estimate rock physical characteristics (i.e., hydraulic conductivity and effective porosity) based on matching of seasonal variations in groundwater elevations. Modeled flow velocities based on these values are typically in the range of 0.03 to 0.3 meters per day (0.1 to 1 feet per day) throughout most of the lobe, although rainy season model velocities within the Moraga Formation rocks beneath Building 25 were as high as 3 meters per day (10 feet per day), reflecting the rise of water levels into high permeability rocks of the Moraga Formation (**Appendix D**).

Groundwater Contamination

The principal Building 25A lobe constituents are halogenated non-aromatic VOCs that were used as cleaning solvents including TCE, PCE, and carbon tetrachloride and their degradation products (e.g., 1,1-DCE, cis-1,2-DCE, and chloroform). Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.6-1** where the

maximum detected concentrations are compared to the target risk-based MCSs. None of the COCs was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.6-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 25A Lobe of the Old Town Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
TCE	304	5	1,594
PCE	37.5	5	343
Carbon tetrachloride	2	0.5	27
1,1-DCE	67.5	6	28,873

Groundwater COC Trends

Concentration trends for total halogenated non-aromatic VOCs detected in wells monitoring the Building 25A lobe (western subplume) are shown on **Figure 4.3.6-4a and 4.3.6-4b**. Groundwater COC concentrations were relatively constant in the source area at Building 25A until initiation of the soil flushing pilot test. Since startup of the pilot test, groundwater COC concentrations have dropped substantially in the wells immediately adjacent to the test, but have not shown consistent trends in other source area wells. Downgradient wells to the west of the source area (i.e., wells MW5-93-10 and MW6-92-17 have shown slow long-term concentration declines over the past 10 years.

The relative proportions of TCE and 1,1-DCE vary with distance downgradient (westward) from the source area. As shown on **Figure 4.3.6-5** and **Figure 4.3.6-6**, the proportion of 1,1-DCE relative to TCE increases significantly with distance downgradient from well MW25A-99-2, located close to the source area, and well MW25A-95-15, located approximately 50 feet downgradient from the source area. However, this relationship cannot be verified in wells further downgradient because parent product concentrations decrease significantly, and degradation product concentrations are below detection levels. The 1,1-DCE may originate either directly as a product spill or from degradation of TCE. If 1,1-DCE is derived from the degradation of TCE,

then the downgradient increase in the relative proportion of 1,1-DCE indicates that degradation is occurring during plume migration. The relative proportions of these constituents have not changed markedly over time, and a slight increase is apparent in the proportion of parent product (TCE) to daughter product (1,1-DCE) in well MW25A-95-15. This indicates that the rate of degradation does not greatly exceed the rate of COC migration from the upgradient source area or dissolution of COCs from residual soil contamination. Based on approximately eight years of monitoring the downgradient edge of the subplume, no downgradient migration of COCs beyond the toe of the plume has been occurring, although this relation is uncertain in the area where the subplume coalesces with the Building 7 lobe.

For the eastern PCE/TCE/carbon tetrachloride subplume, COC concentrations have been essentially constant throughout the monitoring period. Based on approximately eight years of monitoring the downgradient edge of the subplume, no downgradient migration of COCs beyond the toe of the plume has been occurring.

Soil Contamination

Soil samples have been collected in the source area near Building 25A, but only sporadic samples contained detectable VOCs. No PCE was detected, and the maximum detected concentrations of TCE and 1,1-DCE were 0.052 and 0.0058 mg/kg, respectively. These levels are substantially lower than the regulatory-based MCSs. In 1998, soil gas probes were installed west, north, and beneath Building 25A to help locate the source of the groundwater contamination, but no contaminant source was located.

Distribution of DNAPL and Residual Soil Contamination

Maximum concentrations of COCs detected in soil samples collected in the Building 25A lobe area are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**. Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs in the lobe.

The lack of declining concentration trends or changes in relative proportions of COCs in groundwater (prior to startup of the soil flushing pilot test) indicate that residual soil

contamination is probably present within or adjacent to the saturated zone in the vicinity of the source area, although COCs were not detected in saturated zone samples collected during installation of monitoring wells in this area.

4.3.6.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 25A lobe of the Old Town Groundwater Solvent Plume:

- There is no evidence suggesting the presence of DNAPL. The absence of declining trends in COC concentrations combined with the lack of evidence for degradation of COCs in the source area of the western subplume and throughout the eastern subplume indicate that low levels of residual contamination in equilibrium with dissolved groundwater COCs probably remain within the saturated zone. Therefore, corrective measures for the lobe should be based on the remediation of dissolved-phase COCs and low level saturated zone residual soil contamination.
- Concentrations of COCs for both subplumes are at levels significantly lower than target risk-based MCSs.
- Since well yield is generally greater than 200 gpd, regulatory-based MCSs are applicable.

Western Subplume (TCE and 1,1-DCE)

- The western subplume lies within an area where groundwater flows primarily through relatively low permeability rocks of the Orinda Formation close to the source area, and through higher permeability rocks downgradient (west) and crossgradient (north) of this area. Groundwater wells near the source area yield less than 200 gpd, whereas those downgradient and crossgradient yield more than 200 gpd. The estimated groundwater velocity is roughly 0.1 to 1 feet per day.
- Spatial variations in plume chemistry suggest that degradation has been occurring during migration of constituents that are part of the TCE degradation pathway. The lack of temporal change in the relative proportions of COCs indicates that a state of equilibrium has been reached where degradation rates are similar to rates of dissolution of soil contaminants and downgradient migration of dissolved COCs.
- Initial results of the soil flushing pilot test indicate that this method may be effective at decreasing COC concentrations, although no data are available to determine whether permanent concentration reductions are attainable in the absence of continued flushing.

- Migration of COCs beyond the toe of the subplume does not appear to be occurring, and the decreasing concentration trends observed in wells monitoring this area suggest that the subplume may be retreating.

Eastern Subplume (PCE, TCE, and Carbon Tetrachloride)

- The eastern subplume lies within an area where groundwater flows primarily through permeable rocks of the Moraga Formation. This indicates that continued groundwater flow may result in flushing of contaminants from the pore space of the Moraga Formation. Due to the relatively high permeabilities, groundwater extraction wells installed within the plume would be expected to yield more than 200 gpd. The estimated groundwater velocity is up to 9 feet per day in the Moraga Formation. Migration of COCs beyond the toe of the subplume does not appear to be occurring.
- Groundwater COC concentrations are too low to draw conclusions regarding degradation in the eastern subplume. The lack of temporal change in the relative proportions of COCs indicates that a state of equilibrium has been reached where if any degradation is occurring, its rate is similar to rates of dissolution of soil contaminants and downgradient migration of dissolved COCs.

4.3.6.3 Evaluation of Retained Corrective Measures Alternatives

Concentrations of groundwater COCs in the Building 25A lobe exceed regulatory-based MCSs for a number of COCs, but are well below target risk-based MCSs. Since well yield is generally greater than 200 gpd, regulatory-based MCSs are applicable.

Groundwater containing COCs at detectable concentrations has not been migrating beyond the currently defined plume boundary (except possibly where the plume coalesces with the higher concentration Building 7 lobe), so migration control is not a concern. Since COCs are present primarily in groundwater, with only a negligible fraction present as sorbed soil COCs in equilibrium with groundwater, only retained technologies listed in **Table 4.2.3-2** (potential corrective measures technologies for groundwater) are evaluated. The results of the evaluation are provided in **Table 4.3.6-2** and discussed below.

No Action

No action for the Building 25A lobe would consist of terminating all groundwater-monitoring activities and stopping the soil flushing pilot testing the source area. Currently, groundwater concentrations of several COCs (carbon tetrachloride, cis-1,2-DCE, PCE, and TCE)

Table 4.3.6-2. Evaluation of Corrective Measures Alternatives, Building 25A Lobe

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration (c)	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (d)	Regulatory Agency Acceptance	Community Concerns
No Action	yes/no	no	no	yes	2	1	2	5	1	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	yes	yes	3	2	2	4	1	1
Institutional Controls	yes/yes	yes	no	yes	3	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	yes	yes	3	3	3	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/yes	no	yes	yes	3	3	3	3	3	3
Chemical Oxidation	yes/yes	unknown	no	yes	2	3	3	1	5	5
Enhanced bioremediation	yes/yes	unknown	no	yes	3	3	2	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	yes	yes	yes	3	3	4	3	4	4

(a) Level of Compliance Ranking

1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance

1. None
2. Low
3. Partial
4. Moderate
5. High

(c) na; not applicable

(d) relative cost from 1 (high) to 5 (low)

are well above regulatory-based MCSs (MCLs). Groundwater concentrations would remain at levels greater than regulatory-based MCSs for the foreseeable future. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community. It also does not comply with regulatory requirements and is therefore not recommended.

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997. Geochemical parameters measured in well MW25-95-15, located a short distance downgradient from the Building 25A groundwater collection trench, were not favorable for natural degradation processes. In particular, the dissolved oxygen concentration was substantially greater than the minimum concentration that is considered indicative of conditions under which reductive dechlorination of COCs can occur. However, observed ratios of parent-daughter compounds within the western subplume suggest that degradation occurs during downgradient migration. In addition, there is no evidence that natural attenuation is occurring in the eastern subplume. As described above, the lobe has apparently reached a state of equilibrium where the degradation rates are similar to the rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. These observations indicate that MNA would not be an effective alternative unless concentrations of COCs in groundwater in the source area are significantly reduced. Therefore, MNA should only be considered in combination with more aggressive remediation technologies.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The Building 25A lobe is generally stable and no containment or capture is required. Some migration of COCs above regulatory-based MCSs may be occurring where the Building 25A lobe coalesces with the Building 7 lobe; however, at these locations concentrations of

Building 25A lobe constituents are only slightly above MCLs. Continuation of soil flushing and groundwater capture (or implementation of other corrective measures) in the western subplume source area should reduce COC concentrations in the downgradient areas to levels below MCSs. This alternative is therefore not recommended.

Permeable Reactive Barrier /Funnel & Gate

A permeable reactive barrier or funnel and gate system might control migration of COCs into uncontaminated areas to comply with regulatory requirements in areas downgradient from the Building 25A lobe. However, the Building 25A lobe is stable, except possibly where it coalesces with the Building 7 lobe where Building 7 lobe COC concentrations are well above MCLs. This alternative is therefore not recommended.

Chemical Oxidation

Generally, in situ chemical oxidation is applied in areas that have high COC concentrations and is not applicable to broad areas of low level contamination due to the high costs of reagent injection, the need for close spacing of injection points, and because reagent chemistry does not persist during groundwater migration. High COC concentrations or “hot spots” are not present in the Building 25A Lobe, indicating that the technology is unlikely to be cost effective. In addition, the effectiveness of the technology for remediation of the Building 25A lobe is not known and would require pilot testing prior to any full-scale implementation. The method would require numerous closely spaced injection points (typically on the order of 3 to 5 feet spacing). In addition, implementation of this technology would be difficult because for the Building 25A lobe source area is located under Building 25A. For these reasons, chemical oxidation is not recommended.

Enhanced Bioremediation

Available data suggest that natural degradation is only occurring in the downgradient portion of the western subplume. Therefore, the addition of enhancements might be effective in stimulating bioremediation of groundwater COCs in the downgradient portion of the lobe. Hydrogen Releasing Compound (HRC) could be injected to enhance reductive dechlorination of groundwater COCs in both the western and eastern subplumes. However, although pilot testing

of this technology at the Building 71B lobe of the Building 71 Groundwater Solvent Plume has indicated that this method may be effective, its effectiveness at the Building 25A lobe is unknown. Enhanced bioremediation would not be implemented until groundwater COC concentrations in the upgradient lobe area have been reduced to levels that do not migrate to the downgradient area at concentrations above regulatory-based levels.

Soil Flushing and Groundwater Extraction

Available data indicate that DNAPL is not present in the Building 25A lobe and groundwater COC concentrations are relatively low. These characteristics indicate that soil flushing and groundwater extraction may be effective in reducing COC concentrations in the groundwater with minimal “rebound” after flushing is terminated.

After two years of operation of the soil flushing pilot test in the source area, groundwater COC concentrations in wells immediately adjacent to the pilot test area and well MW25A-95-15 have been substantially reduced. However, “rebound” following cessation of flushing has not been evaluated, so it is not yet certain whether concentration declines will be permanent. Based on results of pilot testing, this technology is recommended for full-scale implementation.

Summary of Building 25A Lobe Corrective Measures Implementation Strategy

The remediation objectives for the Building 25A lobe are to: 1) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs do not migrate into areas where concentrations are less than MCSs; and, 2) decrease groundwater COC concentrations below regulatory-based MCSs. The remedial technologies that have been identified that may meet these objectives are MNA, enhanced bioremediation, and soil flushing.

No remediation technologies are needed to address objective (1) above, since long-term groundwater monitoring data have established that the downgradient boundaries of the two subplumes of the Building 25A lobe are not migrating, except possibly where the western subplume coalesces with the Building 7 lobe.

In situ soil flushing has been identified as a potentially effective alternative to address remediation objective (2) above. Based on soil flushing pilot test results, this technology may

permanently reduce COC concentrations to regulatory-based MCSs, and therefore is recommended for full-scale implementation. If in situ soil flushing results in COC concentrations above the regulatory-based MCSs, MNA should be considered to further reduce the concentrations. As described above, the Building 25A lobe has apparently reached a state of equilibrium where the degradation rates are similar to the rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. Soil flushing may reduce COC concentrations sufficiently so that MNA becomes an effective alternative (i.e., the rate of degradation exceeds the rate of dissolution in the upgradient lobe area and migration). Enhanced bioremediation should be considered if MNA becomes ineffective.

4.3.7 Building 69A Area of Groundwater Contamination

The location of the Building 69A Area of Groundwater Contamination is shown on **Figure 4.3.7-1**. The most likely source of the contamination was leakage from a pipeline in the Building 69A Hazardous Materials Storage and Delivery Area (AOC 3-1) that drains to the Building 69A Storage Area Sump (SWMU 3-5). A dislocation was observed in one of the sump drainpipes and repaired in 1987.

4.3.7.1 Current Conditions

Geology and Hydrogeology

Prior to development of the site, the topography of the Building 69A area was generally dominated by relatively steep southward facing slopes. Chicken Creek Canyon, a major north-south-trending drainage course, and its tributaries, occupied the area west of the current location of Building 69A, and flowed downslope towards Building 77. Colluvium greater than 10 feet thick overlies bedrock in the former drainage area. During development, hillside cuts and canyon filling resulted in placement of artificial fill from 25 to 50 feet thick within the canyon in the vicinity of Building 69A. This created the relatively flat site on which Building 69A and adjacent buildings and parking areas are currently located. The main bedrock unit underlying the artificial fill and colluvium in the Building 69A area is the Orinda Formation, which consists of nonmarine siltstones and fine-grained sandstones. The Orinda Formation is overlain in some areas by volcanic and sedimentary rocks of the Mixed Unit.

Shallow groundwater in the Building 69A area is present in both the Orinda Formation and the surficial units (i.e., alluvium, colluvium, and artificial fill). However, groundwater flow within the Orinda Formation is of minor importance, as indicated by the relatively low values of hydraulic conductivity that have been measured in the unit. Depth to groundwater is approximately 25 feet to 45 feet bgs. Assuming a hydraulic conductivity value (K) of 2.6×10^{-7} meters per second for the Orinda Formation (estimated from a slug test in MW69A-92-22) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity (v_x) would be approximately 18 meters per year (45 feet per

year) in the Building 69A area. Groundwater velocities in the surficial units are likely to be greater than this estimate. As shown on **Figure 4.3.7-1**, yields from wells in this area are all less than 200 gpd.

Groundwater Contamination

The principal Building 69A Area of Groundwater Contamination constituents are degradation products of halogenated non-aromatic VOCs that were used as cleaning solvents (e.g., cis-1,2-DCE and vinyl chloride). Lower concentrations of trans-1,2-DCE, PCE, 1,1,1-TCA, and other VOCs, including aromatic hydrocarbons, have also been occasionally detected. Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.7-1** where the maximum detected concentrations are compared to the target risk-based MCSs. Vinyl chloride was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.7-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 69A Area of Groundwater Contamination

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
cis-1,2-DCE	28	6	98,405
vinyl chloride	43	0.5	12
PCE	11	5	343

Note: boldface concentration indicates that the maximum detected concentration of the COC in FY03 exceeds the target risk-based groundwater MCS.

The lateral extent of contamination appears to be confined to a relatively small area west and southwest of Building 69A. The extent of vinyl chloride, which is apparently restricted to the area of temporary groundwater sampling point SB69A-99-1, is much more limited than that of cis-1,2-DCE. Based on the low hydraulic conductivity of the Orinda Formation, the vertical extent of contamination is likely restricted to the colluvium and the upper few feet of the Orinda Formation. No COCs have been detected in downgradient temporary groundwater sampling point SB77-02-1.

Groundwater COC Trends

Concentration variations for cis-1,2-DCE and vinyl chloride in wells monitoring the area of groundwater contamination over time are shown on **Figure 4.3.7-2**. The concentration of cis-1,2-DCE has been decreasing in groundwater samples collected from the three wells monitoring the area of groundwater contamination and is approaching the MCL. However, the concentration of vinyl chloride detected in SB69A-99-1 increased from nondetectable levels to approximately 30 to 40 µg/L in early 2001, coincident with a significant decrease in cis-1,2-DCE concentrations, and has remained relatively constant since that time. The lateral extent of the Building 69A Area of Groundwater Contamination does not appear to have changed over several years of monitoring. However, the observed decrease in cis-1,2-DCE concentrations, in conjunction with an increase in vinyl chloride concentrations strongly suggests that natural degradation processes are occurring (vinyl chloride is a degradation product of cis-1,2-DCE), and that COC concentrations will likely decline to levels below MCLs.

Soil Contamination

Shallow soil samples (2-foot depth) were collected in 1991 in the area west of the groundwater unit to help assess whether chemicals had been released from the likely source, the pipe dislocation described above. The highest VOC concentrations were detected adjacent to the repaired dislocation of the pipe (PCE maximum 2 mg/kg and TCE maximum 0.008 mg/kg), indicating that the pipe was the probable source of the contamination. Soil samples collected in 1992 and 1993 near the repaired pipe dislocation contained PCE at a maximum concentration of 1.4 mg/kg. However, no VOCs were detected in soil samples collected in the same area in September 2000, suggesting that the previously detected PCE and TCE may have degraded to nondetectable levels.

The only other location where halogenated VOCs have been detected in soil samples collected in the area of groundwater contamination was cis-1,2-DCE (0.008 mg/kg maximum) in soil boring SB69A-99-1. However, these soil samples were collected from below the water table, indicating that they may represent groundwater contamination rather than soil contamination.

Presence of DNAPL

Maximum concentrations of COCs detected in soil samples collected in the Building 69A Area of Groundwater Contamination are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**. Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs. The absence of DNAPLs is further substantiated by the decline in total concentrations of halogenated VOCs in groundwater.

4.3.7.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Building 69A Area of Groundwater Contamination:

- There is no evidence suggesting the presence of DNAPL or of residual soil contamination at levels likely to leach into groundwater. Declines in COC concentrations in groundwater corroborate this finding.
- Groundwater flows primarily through surficial units and low permeability rocks of the Orinda Formation at velocities estimated to be approximately 18 feet per year or greater.
- Due to the relatively low permeability of the Orinda Formation, well yields are less than 200 gpd, so target risk-based MCSs are applicable.
- Spatial and temporal concentration trends suggest that cis-1,2-DCE has been degrading, but this process has apparently resulted in local increases in vinyl chloride concentrations. It is anticipated that vinyl chloride levels will not decrease until after the remaining cis-1,2-DCE has degraded further.
- Concentrations of vinyl chloride exceed target risk-based MCSs in groundwater in temporary groundwater sampling point SB69A-99-1. The potential human receptors and risk-based exposure pathways of potential concern are exposure to COCs by hypothetical future indoor workers breathing vapor migrating to indoor air from groundwater (Berkeley Lab, 2003a).

4.3.7.3 Evaluation of Retained Corrective Measures Alternatives

Concentrations of groundwater COCs (vinyl chloride) in the Building 69A Area of Groundwater Contamination exceed target risk-based MCSs. Regulatory-based MCSs are not

applicable. Available data indicate that DNAPLs are not present. No migration of COCs beyond the plume margins is occurring, so migration control is not a concern.

The corrective measures alternatives that are evaluated for the Building 69A Groundwater Solvent Plume and source area are those that were retained in **Table 4.2.3-2** for groundwater). The results of the evaluation are provided in **Table 4.3.7-2** and discussed below.

No Action

No action for the Building 69A Area of Groundwater Contamination would consist of termination of all groundwater monitoring activities. The concentration of vinyl chloride should eventually decrease to below the risk-based level; however, the timeframe for this to happen is unknown. These conditions would require establishment of Institutional Controls to protect future workers. In addition, this alternative would likely be unacceptable to the regulatory agencies and the community. The No Action alternative is not protective of human health and the environment and is therefore eliminated from further consideration.

Monitored Natural Attenuation

The site groundwater monitoring data indicate that biodegradation of halogenated VOCs by reductive dechlorination is occurring. The lines of evidence for this conclusion include:

- The contaminant mass currently consists almost entirely of cis-1,2-DCE and vinyl chloride. The presence of these degradation products suggests biodegradation of PCE and/or TCE. In addition, groundwater samples collected from SB69A-99-1 showed consistent decreases in cis-1,2-DCE concentrations, while concentrations of vinyl chloride have increased.
- Dissolved oxygen (DO) concentrations measured in groundwater indicate that groundwater conditions are anaerobic (DO<1).
- Aromatic hydrocarbons have been detected in groundwater samples. These fuel hydrocarbons could be a carbon source for indigenous microorganisms.

Table 4.3.7-2. Evaluation of Corrective Measures Alternatives, Building 69A Area of Groundwater Contamination

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protection of Human Health and the Environment	Attain MCSs	Control Migration (c)	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (d)	Regulatory Agency Acceptance	Community Concerns
No Action	no/no	no	na	yes	4	4	3	5	2	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	na	yes	4	4	3	4	5	4
Institutional Controls	yes/no	no	na	yes	3	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	na	yes	2	2	2	3	3	2
Permeable Reactive Barrier/Funnel & Gate	no/yes	no	no	yes	2	2	2	3	3	3
Chemical Oxidation	no/no	unknown	na	yes	3	3	3	3	5	5
Enhanced bioremediation	yes/yes	unknown	na	yes	4	4	4	3	5	5
Soil Flushing and Groundwater Extraction	yes/yes	yes	na	yes	3	3	4	3	4	4

(a) Level of Compliance Ranking

1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance

1. None
2. Low
3. Partial
4. Moderate
5. High

(c) na; not applicable

(d) relative cost from 1 (high) to 5 (low)

MNA would include a program to monitor the effectiveness of the alternative. The monitoring program would be based on the existing monitoring well network. Periodic groundwater sampling would provide confirmation that degradation of COCs is continuing, and that vinyl chloride concentrations remain below risk-based levels. MNA is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 69A Area of Groundwater Contamination using the decision factors shown in **Table 4.3.7-2**.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The plume is stable and no containment or capture of the plume boundary is currently required or planned. This alternative is therefore not recommended.

Permeable Reactive Barrier/Funnel & Gate

A permeable reactive barrier or funnel & gate system would have a similar effect to a groundwater capture system. Since the plume is stable and no containment or capture is currently required or planned for the future, this technology is not recommended.

Chemical Oxidation

The effectiveness of chemical oxidation for remediation of the Building 69A Area of Groundwater Contamination plume is not known and would require pilot testing prior to any full-scale implementation. In situ chemical oxidation is generally not effective in low permeability materials such as the Orinda Formation, and as described in Section 4.3.2, pilot testing of this technology in the Building 51L and Building 71B Groundwater Solvent Plume

source areas was not effective, so the likelihood that it would be effective is considered to be low. However, due to the very small size of this unit, this technology could potentially be effective if pilot testing showed that delivery of reagents to the impacted pore space could be ensured. In situ chemical oxidation is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 69A Area of Groundwater Contamination using the decision factors shown in **Table 4.3.7-2**.

Enhanced Bioremediation

Enhanced bioremediation for the Building 69A Area of Groundwater Contamination would consist of the controlled release of Oxygen Release Compounds (ORC[®]) into the groundwater to enhance natural biodegradation of vinyl chloride. A pilot test of HRC injection was conducted at Building 75/75A Area of Groundwater Contamination, under similar site-specific hydrogeologic conditions to those found in the Building 69A area. The results were not favorable, suggesting that enhanced bioremediation is not effective under the hydrogeologic conditions that are present. However, since HRC was the technology that was tested, the effectiveness of ORC is not known. Enhanced bioremediation using ORC is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 69A Area of Groundwater Contamination using the decision factors shown in **Table 4.3.7-2**.

Soil Flushing and Groundwater Capture

Available data indicate that DNAPL and COCs sorbed to the soil matrix in the vadose zone are not present in the Building 69A Area of Groundwater Contamination, except for sorbed COCs in equilibrium with dissolved groundwater COCs. Therefore, groundwater flushing may result in permanent reductions of COC concentrations that are maintained with minimal “rebound” after cessation of flushing. However, the very low permeability of saturated zone materials at the unit would likely limit the effectiveness of this remedy due to the long period of time needed for implementation. In addition, introduction of treated water might result in halting the apparently on-going natural degradation processes. Based on this evaluation, soil flushing is retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 69A Area of Groundwater Contamination using the decision factors shown in **Table 4.3.7-2**.

Summary of Corrective Measures Implementation Strategy

The remediation objective for the Building 69A Area of Groundwater Contamination is to reduce groundwater COC (vinyl chloride) concentrations below target risk-based MCSs. The remedial technologies that have been identified that may meet these objectives are MNA, enhanced bioremediation, chemical oxidation, and in situ soil flushing. Except for MNA, the effectiveness of these technologies would be severely limited by the low permeabilities of subsurface materials. The cost of MNA would be less than the other alternatives that can meet the remediation objective, and except for the short-term effectiveness of soil flushing and enhanced bioremediation, ranked at least as high in the other decision factors listed in **Table 4.3.7-2**. Therefore, based on its ranking in the decision factors and the fact that there is strong evidence that MNA is currently effective, MNA is the recommended alternative.

4.3.8 Solvents in Groundwater South of Building 76 (AOC 4-5)

The location of the Solvents in Groundwater South of Building 76 (Building 76 Groundwater Solvent Plume) is shown on **Figure 4.3.7-1**. The area of maximum VOC concentrations in groundwater south of Building 76 suggests that the primary source of the plume was related to Building 76 operations; however, the specific source has not been located. The Building 76 Motor Pool Collection Trenches and Sump (SWMU 4-3) are suspected to be the primary source of contamination, due to their close proximity to the plume and potential for past releases. The Former Building 76 Gasoline and Diesel Underground Storage Tanks (USTs) (AOCs 4-1 and 4-2) are the likely sources for fuel hydrocarbons that have also been detected in the groundwater south of Building 76.

4.3.8.1 Current Conditions

Geology and Hydrogeology

The Building 76 area lies on a relatively flat graded building pad that interrupts a relatively steep southwest-facing slope. The main bedrock in the Building 76 area is the Orinda Formation, which consists of nonmarine siltstones and fine-grained sandstones. Approximately 10 to 20 feet of fill overlies the bedrock south of the building.

Depth to groundwater is approximately 13 feet to 25 feet bgs. The groundwater is generally in the Orinda Formation and does not extend into the overlying fill. Assuming a hydraulic conductivity value (K) of 3×10^{-8} meters per second for the Orinda Formation (estimated from a slug test in MW76-1) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity (v_x) would be approximately 1.5 meters per year (5 feet per year) in the Building 76 area. As shown on **Figure 4.3.7-1**, yields from wells in this area are all less than 200 gpd.

Groundwater Contamination

The principal Building 76 Groundwater Solvent Plume constituents are halogenated non-aromatic VOCs that were used as cleaning solvents (PCE and TCE) and their degradation

products (e.g., cis-1,2-DCE). In addition, diesel- and gasoline-range hydrocarbons and aromatic (fuel-related) VOCs have been occasionally detected in wells in this area. Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.8-1** where the maximum detected concentrations are compared to the target risk-based MCSs. None of the COCs was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.8-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 76 Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
cis-1,2-DCE	9.8	6	98,405
TCE	20	5	3,065

The plume extends approximately 100 feet southwards from the motor pool area on the south side of Building 76. Groundwater containing COCs lies beneath the existing motor pool gasoline and diesel underground storage tanks and also likely extends beneath Building 76. The lateral (transgradient) extent of halogenated non-aromatic VOCs in the groundwater is characterized by the absence of VOCs in wells to the west and east of the plume (**Figure 4.3.7-1**). The lateral (downgradient) extent of the plume is indicated by only sporadic detections of VOCs in monitoring well MW76-98-22, with no VOCs detected in the well since March 2001. Based on the low hydraulic conductivity of the Orinda Formation, the vertical extent of contamination is likely restricted to relatively shallow depths in the Orinda Formation.

Groundwater COC Trends

VOC concentrations in wells south of Building 76 have remained relatively constant since 1993, as indicated by measurements in monitoring well MW76-1. In addition, COCs have not been detected in downgradient monitoring well MW76-98-22 since March 2001.

Soil Contamination

Soil samples were collected near the Building 76 motor pool collection trenches and garage area sump during several rounds of sampling from 1992 to 1997. In addition, soil samples were collected in 1990 during removal operations for the former Building 76 underground gasoline and diesel storage tanks and in 1997 during subsequent investigations of soil contamination associated with the former USTs. The sampling locations partially overlie the area of groundwater contamination. Relatively low concentrations (well below MCSs) of PCE, TCE, 1,1,1-TCA, Freon compounds, and chloroform were the only halogenated VOCs detected.

Soil Gas and Indoor Air Data

The maximum theoretical ILCR (2.1×10^{-5}) estimated for the unit was within the USEPA target risk range (10^{-4} to 10^{-6}) for current indoor workers, based on indoor air concentrations measured inside Building 76, which partly overlies the area of groundwater contamination (Berkeley Lab, 2003). Benzene, PCE, and TCE were the primary risk drivers. Since benzene was not detected in the groundwater, the source of the benzene is likely the adjacent gasoline fuelling operations. The major source of the halogenated VOCs detected in indoor air may be surface (e.g., concrete) contamination from historical motor pool degreasing activities, and not contaminated soil or groundwater. Soil gas sampling was conducted to assess whether or not VOCs were present beneath the concrete floor of the Building. Soil gas VOC concentrations in the vicinity of the previously collected indoor air sampling data were several orders of magnitude lower than RWQCB ESLs for soil gas. However, two soil gas sampling points at the west end of Building 76 contained elevated levels of PCE (maximum concentration $4,200 \mu\text{g}/\text{m}^3$) that exceed the ESL ($1,400 \mu\text{g}/\text{m}^3$).

Presence of DNAPL

Maximum concentrations of COCs detected in soil samples collected in the Building 76 Groundwater Solvent Plume area are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**. Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs.

4.3.8.2 *Conceptual Model*

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Building 76 Groundwater Solvent Plume:

- There is no evidence suggesting the presence of DNAPL at the unit.
- Groundwater flows primarily through surficial units and low permeability rocks of the Orinda Formation at velocities estimated to be approximately 18 feet per year or greater.
- Due to the relatively low permeability of the Orinda Formation, well yields are less than 200 gpd, so target risk-based MCSs are applicable.
- No data are available to assess whether natural degradation of COCs is occurring.
- Concentrations of COCs are at levels several orders of magnitude lower than target risk-based MCSs.

4.3.8.3 *Evaluation of Retained Corrective Measures Alternatives*

Groundwater well yields at the unit are substantially less than 200 gpd and therefore only target risk-based MCSs are applicable. Since COC concentrations are several orders-of-magnitude less than target risk-based MCSs (**Table 4.3.8-1**) no action is required to attain MCSs. No migration of COCs beyond the plume margins is occurring, so migration control is not a concern. Therefore, No Further Action is recommended for the Building 76 Area of Groundwater Contamination. Since MCSs have been achieved, no comprehensive evaluation of other corrective measures alternatives was completed for this unit.

4.3.9 Building 77 Area of Groundwater Contamination

The location of the Building 77 Area of Groundwater Contamination is shown on **Figure 4.3.7-1**. The Building 77 Sanitary Sewer System (AOC 5-4) was considered the most likely source of the groundwater contamination, based on its location relative to the contamination. Soil and soil-gas sampling conducted along the sewer line, however, could not identify a source area.

4.3.9.1 Current Conditions

Geology and Hydrogeology

Prior to development of the site, the topography of the Building 77 area was generally dominated by relatively steep southward facing slopes. Chicken Creek Canyon, a major north-south-trending drainage course, and its tributaries, bisected the area and flowed beneath the current location of Building 77. During development, hillside cuts and canyon filling resulted in placement of up to 45 feet of artificial fill within the canyon, creating the relatively flat site on which Building 77 is located. The creek has been diverted into stormdrains and emerges just downslope from the road south of Building 77.

Bedrock in the Building 77 area consists of nonmarine claystone, siltstone, and fine-grained sandstones of the Orinda Formation. Several feet of colluvium overlie the bedrock at the base of the former tributary of Chicken Creek. Approximately 40 to 45 feet of fill overlies the colluvium or directly overlies the bedrock where the colluvium is not present.

Shallow groundwater in the Building 77A area is present in both the Orinda Formation and the surficial units (i.e., alluvium, colluvium, and artificial fill). Depth to groundwater is approximately 40 feet to 45 feet bgs. Assuming a hydraulic conductivity value (K) of 4×10^{-9} meters per second for the Orinda Formation (estimated from slug tests south of Building 77) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity (v_x) would be approximately 0.4 meters per year (1.5 feet per year) near the southwest end of Building 77. As shown on **Figure 4.3.7-1**, yields from wells in this area are less than 200 gpd.

Groundwater Contamination

The principal Building 77 Area of Groundwater Contamination constituents are degradation products of halogenated non-aromatic VOCs that were used as cleaning solvents, including cis-1,2-DCE, trans-1,2-DCE, 1,1-DCE, and 1,1-DCA. Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.9-1** where the maximum detected concentrations are compared to the target risk-based MCSs. None of the COCs was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.9-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 77 Area of Groundwater Contamination

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
cis-1,2-DCE	6.1	6	98,405
PCE	9.5 ^(a)	5	343

^(a) Except for an anomalous detection of PCE in August 2003, which was attributed to cross contamination during sampling, concentrations of PCE in MW91-2 have been 1 µg/L or less since 1996.

The lateral extent of contamination appears to be confined to a small area at the southwest corner of Building 77 near MW91-2. Contaminants have not been detected in downgradient, upgradient, or crossgradient wells. Based on the low hydraulic conductivity of the Orinda Formation, the vertical extent of contamination is likely restricted to the fill and the upper few feet of the Orinda Formation.

Groundwater COC Trends

The variations in the concentrations of halogenated VOCs detected MW91-2 over time are shown on **Figure 4.3.9-1**. Concentrations of both total VOCs and the individual chemicals detected in MW91-2 have consistently declined since 1992, with concentrations decreasing to levels below MCLs (trans-1,2-DCE, 1,1-DCE, and 1,1-DCA); or ranging from slightly above to below MCLs (cis-1,2-DCE).

The presence of degradation products and the observed decreases in VOC concentrations strongly suggest that natural degradation is occurring and that concentrations of COCs will continue to decline. Cis-1,2-DCE, trans-1,2-DCE, and possibly 1,1-DCE are probably present as the result of biodegradation of PCE and/or TCE. The presence of 1,1-DCA, and possibly 1,1-DCE, is probably the result of biodegradation of 1,1,1-TCA.

Soil Contamination

In 1996, five shallow soil-gas probes were installed inside the southwest wall of Building 77 to help identify the source of the groundwater contamination. No source area was indicated since only low levels of photoionizable compounds were detected.

Presence of DNAPL

Maximum concentrations of COCs detected in soil samples collected in the Building 77 Area of Groundwater Contamination are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**. Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs. The absence of DNAPLs is further substantiated by the decline in concentrations of both total and individual halogenated VOCs in the groundwater.

4.3.9.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Building 77 Area of Groundwater Contamination:

- There is no evidence suggesting the presence of DNAPL or of residual soil contamination at levels likely to leach into groundwater.
- Groundwater flows primarily through surficial units and low permeability rocks of the Orinda Formation at velocities estimated to be approximately 1.5 feet per year.
- Due to the relatively low permeability of the Orinda Formation, well yields are less than 200 gpd, so target risk-based MCSs are applicable.
- Declining concentration trends and the presence of degradation products indicate that natural attenuation of COCs is occurring at the unit.

- Concentrations of COCs are several orders of magnitude less than target risk-based MCSs. Concentrations of COCs have declined to levels below or only slightly above MCLs, with all concentrations below MCLs some quarters.

4.3.9.3 Evaluation of Retained Corrective Measures Alternatives

Groundwater well yield at the unit is less than 200 gpd and therefore, only target risk-based MCSs are applicable. The groundwater concentration data indicate that natural attenuation processes have been effective in reducing concentrations of COCs in the Building 77 area to several orders-of-magnitude below target risk-based MCSs and also below MCLs. Concentrations of the four VOCs consistently detected, trans-1,2-DCE, 1,2-DCE, cis-1,2-DCE, and 1,1-DCA, were below MCLs three of the five quarters MW91-2 was sampled from September 2001 through August 2003. No migration of COCs beyond the plume margins is occurring, so migration control is not a concern for the unit. Therefore, No Further Action is recommended for the Building 77 Area of Groundwater Contamination. Since MCSs have been achieved, no comprehensive evaluation of the other corrective measures alternatives was completed for this unit.

4.3.10 Building 75/75A Area of Groundwater Contamination

There are two relatively small areas where halogenated VOCs have been detected in the groundwater near Buildings 75 and 75A (**Figure 4.3.7-1**). The first area extends southward from the east side of Building 75A toward Building 75. The second area is located between Building 75 and 75A. The two areas may commingle near the northeast corner of Building 75. Collectively these areas have been designated the Building 75/75A Area of Groundwater Contamination. The different suites of chemicals detected in groundwater east and south of Building 75A indicate separate sources for the contamination. The contamination may be related to operations of the Building 75 Former Hazardous Waste Handling and Storage Facility; however, the source has not been confirmed since only relatively low concentrations of COCs have been detected in the soil in the area.

4.3.10.1 Current Conditions

Geology and Hydrogeology

The main bedrock unit that underlies the Building 75/75A area is the Orinda Formation, which consists of nonmarine siltstones and fine-grained sandstones. Overlying the bedrock is approximately 20 feet of colluvium, consisting of clay, which is in turn overlain by approximately 12 feet of sandy-clay fill material.

Depth to groundwater varies from approximately 15 to 28 feet bgs. Assuming a hydraulic conductivity value (K) of 4×10^{-7} meters per second for the Orinda Formation (estimated from a slug test in MW75-98-15) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity (v_x) would be approximately 9 meters per year (30 feet per year) in the Building 75/75A area. As shown on **Figure 4.3.7-1**, yields from wells in this area are all less than 200 gpd.

Groundwater Contamination

The principal Building 75/75A Area of Groundwater Contamination constituents are halogenated non-aromatic VOCs that were used as cleaning solvents, including TCE and degradation products (e.g., 1,1-DCE, and cis-1,2-DCE). Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.10-1** where the maximum detected concentrations are compared to the target risk-based MCSs. None of the COCs was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.10-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 75/75A Area of Groundwater Contamination

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
<i>Contamination East of Building 75A</i>			
TCE	16.0	5	1,594
cis-1,2-DCE	52	6	98,405
PCE	15.2 ^(a)	5	343
<i>Contamination South of Building 75A</i>			
PCE	46 ^(a)	5	343

^(a) Anomalous detections of PCE and TCE in 2003 may have been the result of cross contamination during sampling. PCE has generally not been detected in wells in this area

The upgradient and transgradient extent of the groundwater contamination is characterized by the absence of COCs in monitoring wells to the north and west of Building 75A, and wells further east and southeast of the unit (**Figure 4.3.7-1**). Based on the low hydraulic conductivity of the Orinda Formation, the vertical extent of contamination is likely restricted to the fill and the upper few feet of the Orinda Formation.

Groundwater COC Trends

Concentrations of cis-1,2-DCE have declined somewhat in MW75-96-20, while concentrations in SB75-02-1 appear to be increasing. Both of these wells monitor the area of

groundwater contamination east of Building 75A. The relatively high concentration of cis-1,2-DCE in SB75-02-1 suggests that biodegradation of PCE and/or TCE is occurring.

Soil Contamination

Halogenated VOCs were detected in soil samples collected between Building 75 and Building 75A in 1997 during closure activities associated with the former Building 75 Former Hazardous Waste Handling Facility, and in 2002 east of Building 75A as part of a groundwater contamination source investigation. Maximum concentrations of COCs detected are listed in **Table 4.3.10-2**. All concentrations are well below the target risk-based MCSs. Regulatory-based MCSs for soil are not applicable since well yields are less than 200 gpd.

Table 4.3.10-2. Maximum Concentration of VOCs Detected in Soil Samples, Building 75/75A Area of Groundwater Contamination

COC	Maximum Concentration (mg/kg)	Target Risk-Based MCS (mg/kg)
PCE	0.31	0.45
TCE	0.061	2.3
cis-1,2-DCE	0.43	38
trans-1,2-DCE	0.021	50
1,1,1-TCA	0.015	690
1,1-DCE	0.006	8
Methylene chloride	0.02	1.8

The maximum concentrations of the detected VOCs were generally found in the samples collected east of Building 75A. This is the location that is considered the primary source area for the VOCs detected in the groundwater east of the building.

Presence of DNAPL

Maximum concentrations of COCs detected in soil samples collected in the Building 75/75 Area of Groundwater Contamination are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**, . Similarly, concentrations of COCs in groundwater are

very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs.

4.3.10.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Building 75/75A Area of Groundwater Contamination:

- There is no evidence suggesting the presence of DNAPL.
- Groundwater flows primarily through surficial units and low permeability rocks of the Orinda Formation at velocities estimated to be approximately 30 feet per year.
- Due to the relatively low permeability of the Orinda Formation, well yields are less than 200 gpd, so target risk-based MCSs are applicable.
- The presence of degradation products indicate that natural attenuation of COCs is occurring at the unit.
- Concentrations of COCs in groundwater are several orders of magnitude less than target risk-based MCSs.

4.3.10.3 Evaluation of Retained Corrective Measures Alternatives

Groundwater well yields at the unit are substantially less than 200 gpd. Therefore, only target risk-based MCSs are applicable, and COC concentrations are all several orders-of-magnitude less than target risk-based MCSs (**Table 4.3.10-1**). No migration of COCs beyond the plume margins is occurring, so migration control is not a concern. Therefore, No Further Action is recommended for the Building 75/75A Area of Groundwater Contamination. Since MCSs have been achieved, no comprehensive evaluation of other corrective measures alternatives was completed for this unit.

4.3.11 Benzene Detected in Groundwater in Wells East of Building 75A

Benzene has been detected in two relatively deep monitoring wells (MW91-4 and MW75A-00-7) on the east side of Building 75A. The locations of the wells are shown on **Figure 4.3.7-1**. The wells are screened within the Orinda Formation from approximately 115 to 145 feet below ground surface. The source of the benzene is not known; however, given the fact that benzene has also been detected in other deep wells screened in the Orinda Formation, there is a possibility that the benzene could be naturally occurring.

4.3.11.1 Current Conditions

Geology and Hydrogeology

The main bedrock unit that underlies the Building 75/75A area is the Orinda Formation, which consists of nonmarine siltstones and fine-grained sandstones. Overlying the bedrock is approximately 20 feet of colluvium, consisting of clay, which is in turn overlain by approximately 12 feet of sandy-clay fill material.

Depth to groundwater varies from approximately 15 to 28 feet bgs. Assuming a hydraulic conductivity value (K) of 4×10^{-7} meters per second for the Orinda Formation (estimated from a slug test in MW75-98-15) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity for the shallower section of the Orinda Formation (v_x) would be approximately 9 meters per year (30 feet per year) in the Building 75/75A area. The velocity in the deeper section where the benzene has been detected would be much less. Well yields from both MW91-4 and MW75A-00-7 are much less than 200 gpd and therefore risk-based MCSs are applicable.

Groundwater Contamination

Benzene has been detected in MW91-4 and MW75A-00-7 most quarters the wells have been sampled. Benzene is generally the only VOC detected in either well. Benzene has not been detected in two monitoring wells (MW75-99-7 and MW75-96-20), which are within approximately 14 feet of the deeper wells, but screened above a depth of 50 feet. The maximum concentration of

benzene detected in each well in FY03 is listed in **Table 4.3.11-1** where the maximum detected concentrations are compared to the target risk-based MCS. Benzene has not been detected at a concentration above the target risk-based MCS.

Table 4.3.11-1. Maximum Concentrations of Benzene Detected in Groundwater in FY03 in the Building 75A Area

Well Number	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
MW91-4	11	1	175
MW75A-00-7	47	1	175

Groundwater COC Trends

The detected concentration of benzene in MW91-4 has ranged from 3.6 µg/L to 98 µg/L, with no apparent trend in the data. Concentrations in MW75A-00-7 have ranged from 10 and 47 µg/L, also with no apparent trend in the data.

Soil Contamination

The only location where benzene has been detected in soil samples near Building 75A was at a depth of 140 feet at MW75A-00-7.

Presence of DNAPL

The concentration of benzene in groundwater is very low relative to its solubility and effective volatility, providing no evidence for the presence of DNAPL.

4.3.11.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Benzene Detected in Two Wells East of Building 75A:

- There is no evidence suggesting the presence of DNAPL.
- Groundwater wells in which the benzene has been detected yield less than 200 gpd, so target risk-based MCSs are applicable.

4.3.11.3 *Evaluation of Retained Corrective Measures Alternatives*

Groundwater well yields at the unit are substantially less than 200 gpd. Therefore, only target risk-based MCSs are applicable, and benzene concentrations are several orders-of-magnitude less than target risk-based MCS (**Table 4.3.11-1**). Therefore, No Further Action is recommended for the Benzene Detected in Groundwater in Two Wells East of Building 75A. Since MCSs have been achieved, no comprehensive evaluation of other corrective measures alternatives was completed for this unit.